THE RICE INSTITUTE PAMPHLET

Vol. III April, 1916 No. 2

Published by

THE RICE INSTITUTE

A university of liberal and technical learning founded by William Marsh Rice in the City of Houston, Texas, and dedicated by him to the advancement of Letters, Science, and Art

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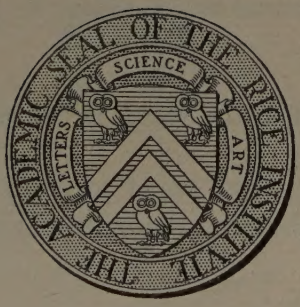

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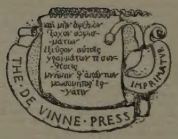
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THE GEOLOGY OF TEXAS

I

ITS PART IN THE BUILDING OF A CONTINENT

IN a study of the origin and growth of the earth, whether we hold with the advocates of the Nebular Hypothesis, which has so long been the accepted theory of the development of our solar system, that the earth as we now know it cooled gradually from a gaseous state to a solid or partially solid condition, or incline to those later geologists who have presented in the place of this older theory the Planetesimal Hypothesis, which supposes that the earth has grown to its present size largely through the accretion of solid matter from planetary space, we come finally to that point where what has, in either case, been almost purely hypothetical reasoning gives place to facts of observation.

The face of the earth, with its plains and mountain ranges, its natural gorges and the many openings made by man, permits us to study a part at least of the materials which form its crust. Where we find our exposures of the earliest rock formations which appear on or near the surface of the earth, there we begin our observational geology.

While the two hypotheses may differ as to origin and previous conditions, both agree that the earliest visible rocks are the product of vulcanism and that they mark the culmination of this force as the dominant factor in rock formation and usher in the era of sedimentation. They are agreed, too, that even at the time of the early existence of these rocks as the surface material of the earth the pattern of the world

was already fashioned, the foundations of the continents were laid, and the ocean beds were hollowed out, although probably not in exactly the same relations that they hold to-day.

Changes there have been. The surface of the continents has had its numerous periods of emergence when they spread, as mountain and plain, high above the level of the sea, followed by similar periods of submergence, when they were in part buried deep beneath its waves. Likewise the ocean's depths have varied greatly, from time to time, and parts now many fathoms below the surface have had periods as land areas and teemed with the animal and vegetable life of their day. Cataclysms have marked some of these changes, but many have been so gradual that they could hardly be suspected were their records not written indelibly in the rocks.

These changes are the milestones which mark the road the geologist must travel in search of the truth concerning the origin and growth of the countless alternations of rock and sand and clay which constitute the earth as we now know it, and of the myriad forms of life which peopled this globe before our advent upon it.

The surface material of the continental area at the time when erosion and sedimentation began to be the potent factors in earth building, consisted of this series of volcanic rocks only, and the general attitude of the land area at that time must be inferred from the present exposures of these rocks and their relations to the earliest sedimentaries.

In North America, save in the region lying north of the Great Lakes, these early rocks are now largely covered by rocks of later formations; but there are areas enough in which they are exposed, or in which they are so near the surface that their presence can reasonably be inferred, to

mark out the general surface conditions of that time and give us lines along which to trace the history of the following ages.

As recognized by American geologists, the principal exposure of these basal rocks on the North American continent is found in a great V-shaped body trending northeast and northwest from the Great Lakes. This is known as the Great Northern or Canadian shield.

If the line marking the eastern border of this shield be extended southwestwardly, we find directly in its course the exposures of similar rocks at Pilot Knob, Missouri, and in the Llano region of Texas. To the westward of the latter we find again in the trans-Pecos area other exposures of the same rocks, and these are the southern extremity of the great belt of similar material of the Rocky Mountain region that stretches northwestward into Alaska, approximately paralleling the western border of the Canadian shield, thus forming a second V-shaped figure, the lines of which are closely conformable with the first.

To the east of the main body of the shield and also approximately parallel with the direction of its eastern margin, a series of outcrops of similar rocks, known as the Appalachian belt, extend from Newfoundland to Alabama.

On the Pacific Coast we find still another belt of these exposures which, beginning in southern California and Arizona, trend southwestward along the western margin of the Sierra Madre through Mexico, in effect marking the southwestern border of the continent as the Appalachian marks its eastern limits.

If we project the axial line of the Appalachian belt southwestward it will meet the Pacific belt south of Manzanillo, and such an extension would form a third V, the lines of which would approximately parallel the other two.

These lines of outcroppings of our earliest rocks, trending northeast on the Atlantic side and northwest on the Pacific side, form what Dana calls the protaxes of the continent.

In the depressions occupying some part of the space between these several protaxes were gathered the waters of the first epi-continental seas, and the detritus arising from the erosion of the land areas was carried down and deposited in them as well as in the oceans that washed the shores of their outer slopes.

Thus these protaxes give the dominant structural lines along which development proceeded, and those portions we see to-day are only the vastly attenuated remnants of the great land areas which existed in the beginning of the geologic record, since it was from their mass that the greater portion of the material was derived which filled the intervening troughs with thousands upon thousands of feet of sedimentary sands and clays.

That area which is of especial interest to us at this time is located at the southern extremity of those ancient elevations which formed the second or central V. We had in this region, in the beginning of sedimentary deposition, a broad belt of crystalline rocks extending from the Colorado to the Rio Grande, reaching southward an unknown distance into the waters of the ocean, and enclosing within its arms northeast and northwest an area to be later occupied by a long succession of continental seas.

This belt of crystalline rocks formed a barrier, therefore, more or less complete, between the waters of the interior sea and those of the open ocean, a barrier which afterward at different times was broken through or even entirely submerged. Consequently, the connection of the present exposures of the central and west Texas areas with each other is now deeply buried beneath the accumulated sediments of

later formations, as is also such connection as may have existed with Pilot Knob and the Nucleal V to the northeast and in some measure with the Rocky Mountains to the northwest, yet the overlying beds give evidence that such connection did exist and that the lines as here drawn have been and are the dominant ones for this particular region.

This ancient belt of crystalline rocks is known to us now only by remnantal patches. At the eastern extremity we have the Llano granites, gneisses, and schists exposed over an area some sixty miles in length by forty miles or more in width.

Going westward for three hundred miles, we find only the limestones of the Cretaceous mantling all else until we reach the trans-Pecos country. In this region the Rocky Mountain protaxes are now represented by four separate lines or belts of mountainous elevations separated by broad valleys filled with comparatively recent deposits. In each of these belts we find areas of exposures of pre-Cambrian rocks similar to those of the Llano region, and these exposures, beginning on the Colorado and ending on the Rio Grande, all occur along a line approximately N. 75° W., which is that determined by Comstock as being the primary and fundamental structural trend of his Burnetan (or the basal granites and gneisses) of the Llano area, and which is also approximately the direction of the main structural axis of the Wichita and Arbuckle mountain masses, of similar age, lying to the northward of our area.

The Llano rocks include gneisses, schists, and granites with bands of crystalline limestone, quartz porphyry, serpentine, etc.

In the Apache mountains the pre-Cambrian rocks comprise granites, schists, and crystalline limestones.

The Diabolo-Van Horn region shows below the Cam-

brian sandstones, schists, quartzites, conglomerates, crystalline limestones, granites, and igneous intrusions.

In the Franklin mountains, however, the basal rock of the pre-Cambrian is a great deposit of quartzite which is overlain by rhyolitic conglomerate and rhyolite porphyry, such granite as occurs being considered to be of much later age.

In addition to these exposures, crystalline rocks also appear at points between them, and although their exact relations have not been fully determined, it is highly probable that they will similarly be found to be parts of the original belt.

It was Comstock's belief that some of the older rocks of the Llano region were in reality a part of the original Archean land mass, and, from my own observations, both in Llano and in west Texas, I am inclined to agree with him, and believe that when the matter is fully worked out it will be found that such masses can be differentiated in both areas. Later investigators, however, have given a different interpretation to the conditions found, and claim that the rocks are probably not older than the Eparchean or Algonkian. However this may be, even if the very earliest rocks are no longer uncovered, we have in these exposures in central and western Texas, masses of the earliest known sedimentaries, which were certainly derived in large part from such Archean land mass, and were subjected to vulcanism, intruded by eruptive material, metamorphosed into gneiss, schists, and marble, and strongly folded and eroded prior to the beginning of the deposition of any of those beds containing definite traces of fossil remains which now mark the earliest stage in historical geology.

Thus began the building of this portion of the continent,

and with the emergence of these areas and the ushering in of the long time of sedimentary deposits which followed, vulcanism seems to have died out almost entirely, and we find no traces of eruptive materials in any of the overlying beds until after the Carboniferous.

At the beginning of the Paleozoic we had as land surfaces the areas mentioned, which were undoubtedly of much greater extent than at present. No sediments of earlier Paleozoic time are known in this region, the lowest deposits of the west being the Bliss sandstone, which is referred to the middle or upper Cambrian, and the Hickory sandstone in the east, which is clearly of upper Cambrian age. It is therefore apparent that through earlier Paleozoic time our area continued above the sea, and in the Llano region we find that the surface was worn comparatively smooth in many places prior to its submergence.

The waters transgressed from the westward and first engulfed the El Paso region in middle Cambrian times, but did not reach the Llano lands until the upper Cambrian.

In the west the Bliss sandstone, which has a thickness of 300 feet, is the only Cambrian deposit so far positively recognized, although Richardson suggests the possible upper Cambrian age of the lower portion of the El Paso limestone. The Bliss sandstone occurs in the Franklin, Hueco, and Diabolo mountains, but it is not always present between the pre-Cambrian rocks and the overlying Ordovician, which in places is found resting directly upon the pre-Cambrian.

In the Llano region the first deposits in the encroaching sea were the sandstones of the Hickory series. As the water deepened these were followed by greensands, shales, and shaly limestones, succeeded by a more massive limestone with chert. This sedimentation apparently continued with-

out serious interruption; and although the base is upper Cambrian and the top as shown by its fossils is lower Ordovician, no hard and fast line can be drawn between the two.

This massive limestone marks the close of deposition in this area at this time.

The total thickness of the rocks in the Llano region now recognized as belonging to the Cambrian and Ordovician is about 1600 feet. They are found entirely surrounding the old granitic core, and their relations to it clearly indicate that at the time of their deposition this area was an island in the Cambro-Ordovician sea. Furthermore, nowhere in this area have there been found any deposits of an age intermediate between this Ordovician limestone and the overlying limestone which contains fossils of the Pennsylvanian series of the Carboniferous; from which fact we infer the recession of the sea immediately following the deposition of the Ordovician, leaving this entire area dry land.

In the west the conditions were different. In the Franklin mountains we find resting upon the Bliss sandstone not only a limestone having a thickness of 1000 feet or more with lower Ordovician fossils, but overlying this another limestone 400 feet in thickness with fossils of middle and upper Ordovician age, and following this again, without any apparent unconformity or sensible break in deposition, 1000 feet of other limestones with Silurian fossils, proving that the western end of the belt continued under water until at or near the close of the Silurian.

Similarly in the Diabolo region the lower Ordovician is followed by limestones carrying fossils of upper Ordovician age.

The Ordovician which occurs in the Caballos mountains near Marathon contains fossils of the Trenton stage, and is possibly followed in that locality also by Silurian beds as in

the Franklin and Diabolo mountains, although, up to the present, distinctive fossils from the deposits supposed to be of this age have not been brought to light.

With the close of the Silurian the waters receded from this portion of Texas also.

As next recorded, our history begins with the Pennsylvanian deposition. Of the happenings in and around the Llano region through that long interval of time in which was laid down, in other areas, the vast thickness of sediments now referred to the middle and upper Ordovician, the entire Silurian and Devonian systems and the Mississippian series of the Carboniferous, we have now no trace and must conclude that during this period the Llano region was a land area or that such sediments as may have been laid down had been eroded prior to the beginning of the Pennsylvanian.

So also to the west, since we have no records between the Silurian and the Pennsylvanian, we infer a land area during that period, or such uplifts and erosion of the area as removed the few sediments that may have been laid down.

No visible evidence in the way of outcrops exists at this time to show the exact condition of the region lying between these two known land areas, but it is more than probable that it was also land and that as such it continued to be a barrier separating the waters of Gulf and Ocean of the south from those of the central seas to the north, not only during the long interval of time as shown by the recording sediments already mentioned, but through the entire Paleozoic and much of the Mesozoic as well.

This is indicated by the fact that the formations occurring to the north of this belt, which are earlier than the Cretaceous, are all directly connected with or entirely similar to those of the interior seas, while directly south of this

belt no such formations are known to occur, and such as do occur in its western extension or which have been found by drilling along its southern border show that they were laid down in the open waters of the Gulf or Ocean.

Therefore, for a period of time covering much more than one-half the great span occupied in building the earth from the beginning of sedimentation to its present condition, the belt of territory which we have been considering was itself a land area.

This area, which took its form in the very beginning of known geologic time, which gave of its materials to build the territory surrounding it, and which has from the beginning until now exercised so great an influence upon the character of the sediments and the shaping of this portion of the continent, should, it seems to me, be now clearly recognized despite the fact that it is at present visible in exposures of its own materials only at its eastern and western extremities.

With the incursion of the Pennsylvanian sea, deposition again became active over a large portion of the State.

The earliest deposits noted are those now exposed on the eastern margin of the Llano region, consisting of limestones and shales. On the southeastern margin of this region, in Burnet county, both the limestone and its overlying shale are found. Along the southern margin, in Gillespie county, at the falls of the Pedernales, and in Spring creek, the only exposures observed are those of the limestone. To the northeast exposures of these limestones and shales are found from Lampasas westward to the Colorado river and following the valleys of the San Saba and Richland creek to or beyond the mouth of Brady creek.

These beds, except where disturbed by faulting, dip away from the old Llano headland on all sides. From the vicinity of Bend on the Colorado river, where these beds were

first described, there appears to be a geanticlinal fold in these rocks running northeastward through Lampasas county, which was developed prior to the beginning of the overlying Coal Measures, and this fold shut out the Gulf waters from the interior region.

East of this fold these limestones and shales are succeeded directly by the Cretaceous; west of it, by the Coal Measures of the Upper Pennsylvanian and by the Permian deposits.

The succeeding sediments of this portion of the State are entirely unconformable with those of the Bend, and were deposited in an interior sea which stretched northward into Oklahoma and Indian Territory. They comprise the sands, clays, limestones, and coal of the later Coal Measures, and the sands, clays, limestones, and gypsum beds of the Permian which overlie them.

The southern margin of the sea is clearly shown along the northern border of our ancient land mass in San Saba county, and many of its bays and headlands are clearly distinguishable to-day. Its eastern margin was probably a land mass lying east of the Lampasas geanticlinal. The land areas of the Arbuckle-Wichita mountains formed its northwestern shore, and there was probably another land mass in the west having somewhat the position of the present Llano Estacado.

The northern and southern shore lines are clearly shown by the character and dip of the deposits adjacent to them, but the others can only be inferred at this time.

We know from the variable character of the deposits along the eastern part of the area that this side of the sea was subject to changes of level due to the influx of water or the elevation or depression of the earth's surface, which gave variously open sea conditions when limestones were

laid down, alternating with shallower water in which were deposited sands and clays derived from the adjoining land, and with swamp conditions which permitted the formation of coal.

Toward the close of Pennsylvanian time this sea gradually shallowed and brought in the period of the Permian red clays and sands and meager limestones. And these, as the sea gradually dried up, gave place to the great gypsum deposits which marked the desiccation of this sea and the close of the Carboniferous epoch.

The conditions in the trans-Pecos region during the Carboniferous and Permian were markedly different. During its long emergence the old land mass had apparently been worn down to a nearly even surface; and as the waters of the Pennsylvanian sea, which came in from the west and south, covered it, there was first laid down a conglomerate of the regulus of the materials directly underlying, whether they belonged to the granites, schists, etc., of the pre-Cambrian or to the sandstones or limestones of the older Paleozoic; and this was immediately followed by limestones which are clearly of marine origin, and no deposits occur which could have been brought in from adjacent land areas. These limestones have a thickness of more than 3000 feet, thus indicating the long continuance of comparatively stable conditions suitable for their deposition. They are known as the Hueco limestone.

Large areas of these limestones are now exposed in the various mountain masses and ranges of the trans-Pecos area, and they can be seen in buttes and mesas along the railway lines.

So far as known, the Hueco limestones have not been observed east of the Diabolo mountains, and it is possible that they were limited on the east by the supposed land mass

which formed the western border of the interior Carboniferous sea.

On their eastern border these Hueco limestones were followed by others which are referred to the Permian, but exact contacts have not yet been found.

In the Guadalupe mountains the Permian deposits comprise the Delaware mountain beds, which toward the north are prevailingly sandy with thin limestone bands, but southward in the main mass of the mountains consist almost entirely of limestone with only minor strata of sand. These have a thickness of 2200 feet and are overlain by 1800 feet of El Capitan limestone. These limestones carry an abundant and characteristic marine fauna entirely different from any yet found in the interior. So far the only other occurrence of such fossils known is in the Presidio region, more than 100 miles to the south of the Guadalupes. It is therefore apparent that during the early Permian in this western area the sea was still open to the south, and that on the north and east there existed a land barrier.

Following the deposition of these limestones, but still within Permian time, the Guadalupe and Delaware mountain masses emerged from beneath the sea and became a land area. The barrier which had existed to the east was eroded or submerged and the interior sea extended to the base of the Guadalupes, so that the continuations of the upper beds of the Permian of the interior area with their gypsum deposits were laid down here also, and thus the interlapping of these different types of deposits of the east and west is found in the valley of the Pecos river.

This marks the close of the Paleozoic era, and the earth movements of that time brought the largest portion of the State as we now know it above the waters of the sea, and it is probable that parts of it have never again been engulfed.

So far as we can judge from conditions now known, the Mesozoic began with Texas as a land area and so continued through the Triassic, Jurassic, and earliest Cretaceous.

During some portion of the Triassic a large fresh-water lake occupied the area of the present Llano Estacado and extended northward for some distance. In its sediments we find vertebrate remains through which its age is definitely established, and in addition vast quantities of true *Unios* are found, this being the first appearance of these fresh-water bivalves upon the globe so far as now recorded.

In the Malone mountains southeast of El Paso there are some limestone beds which show that the oceanic or gulf waters covered an area of unknown extent in that vicinity in Jurassic time.

The character of the deposits and the fossils contained in them indicate that they were laid down near shore, and it is probable that the original area was not large. So far as we have yet found, this is the only exposure of deposits of Jurassic age in Texas. Their presence, however, in the connection in which we find them indicates the beginning of the great submergence which reached its culmination during the succeeding Cretaceous era, and by which practically the entire Texan land area was covered by the waters of the Southern ocean.

During the early Mesozoic deposition was very active in central Mexico and seems to have been practically continuous through the Triassic, Jurassic, and lower Cretaceous. The study of the rich fauna which has been collected by the Geological Survey of Mexico shows transition beds between the Jurassic and the Cretaceous followed by the entire lower Cretaceous column.

Coming in from the south, the sea first reached our borders in the region of Presidio del Norte, and here were de-

posited the gravel and sand which constitute the lowest beds of this age of which we have knowledge in the southwest, but which the Mexican geologists claim are somewhat higher in the section than the lowest Cretaceous beds existing there, showing that some interval of time was required after the commencement of the Cretaceous deposition for the advancing sea to reach our territory.

The lowest division of the Texas Cretaceous is known as the Trinity. In its fullest development it consists of three members called in their ascending order Trinity sand, Glen Rose limestone, and Paluxy sand. When the members are all present they indicate a gradual deepening of the sea in that locality until the end of the Glen Rose followed by shallower waters in the Paluxy. There are, however, many places where only sands are found, and it is sometimes difficult to know whether these are Trinity or Paluxy. Where fossils occur in them there is less trouble, since those of the Trinity are oysters or other marine forms, while the Paluxy is usually characterized by plants and fossil wood.

West of the Guadalupe mountains the advance of the waters was very slow, and during the entire Trinity deposition they did not reach northward beyond our old barrier. The sands of the ridges just north of Sierra Blanca are the most northerly outcrops we can now refer to this age.

To the east of the Guadalupes, however, a different story is told. The Trinity ocean spread more rapidly east and north, and, engulfing the old barrier between the Guadalupes and the Llano region, reached northward over the Staked Plain and into Colorado and eastward into Arkansas.

North of Kent there are extensive deposits of Cretaceous sands which from the large amount of fossil wood we consider Paluxy. The sands may be the worked over sands of the upper Permian beds and the trees may have come from

the wooded slopes of the Guadalupe mountain area. The Trinity is also found along the scarp of the Staked Plain and in the detached buttes and mesas lying north and east of it, but the sands thin rapidly toward the north.

The Llano mountains alone remained as islands in this Trinity sea, which entirely surrounded them. This is proved by the fact that in many places later beds of the Cretaceous are found resting upon the rocks of this region, the sands being entirely absent.

The beds of sand so deposited were destined to be of incalculable value to us, since they are now the source of the artesian water of north and central Texas and furnish the supply that through the series of great springs or natural artesian wells yields such abundant flows from Del Rio to Georgetown and is the source of the San Marcos, Comal, Guadalupe, and San Antonio rivers.

In the gradually deepening waters which followed were laid down the limestones of the Comanche Peak and Edwards subdivision of the Fredericksburg over an area even wider than that of the Trinity. Throughout this area the Edwards limestone, by reason of its ability to resist erosion, forms the surface rock over perhaps as large a territory as any other single formation in the State.

West of the Guadalupes, as before, the Fredericksburg sea beat almost in vain against the south shore of our barrier land, and all deposits now known are of comparatively deep-sea character and with few exceptions lie south of the railroad line.

East of the Guadalupes the waters were able to reach into the interior, and, as with the Trinity, we find the Edwards limestone in the scarp of the Plain, and to its hardness and protective covering are due the outlying buttes and mesas to the north and east.

It is found surrounding the Llano region on all sides and is thought by some to have covered that area as well. It is true that its present relations to the older rocks give considerable weight to this idea; but, when we consider at the same time that there are granite peaks along the southern border of the region which are surrounded by the limestone in such manner as to indicate that they at least were never covered, it would seem probable that not even in Fredericksburg time was the Llano region entirely submerged.

The Washita deposits which followed the Fredericksburg, and which are in part very similar to them, are for the most part more marly in character and carry a variable amount of clayey material in connection with the limestones. This variable character of its deposits in different localities marks like variations in the conditions there existing during the time in which they were laid down. South of Sierra Blanca no appreciable break was found between the Fredericksburg and the Washita, and certain fossil forms such as the *Caprina* which are characteristic of the Fredericksburg in central Texas continued up into the Fort Worth limestone in this region and are also found as far east as the Devil's river, indicating that the deeper sea continued here through both Fredericksburg and Washita, while the deposits which extend up the Pecos trough correspond in a general way with the shallower water deposits of central and north Texas.

Similar conditions to those which existed in our trans-Pecos region during Fredericksburg and Washita times extended westward as far as Bisbee, Arizona, where we find similar beds and the same fossils.

Overlying the Fort Worth limestone there is a bed of clay with thin limestone partings which, while only 75 feet in thickness, forms a belt which extends with only slight intermissions from Red river to the Rio Grande. It is called

the Arietina or Del Rio clay. It is followed by a bed of limestone of even less thickness in most exposures, which is characterized by its peculiar mottling and its fossils and is known as the Vola or Buda limestone. The Arietina throughout this area shows by its materials the shallow sea and near shore conditions, the overlying limestone a recurrence of deeper waters immediately preceding the emergence which marked the close of lower Cretaceous sedimentation of which the Vola is the latest member.

The fact that the lower Cretaceous did not submerge our barrier west of the Guadalupes is well attested by the exposures that exist. Beginning on the Rio Grande south of the Malone mountains, we have the small exposure of the Jurassic capped by the Trinity and Fredericksburg. A few miles to the northward the Fredericksburg rests directly upon the Pennsylvanian limestones, and still beyond the Washita rests upon the same limestones without the presence of either Trinity or Fredericksburg, proving the very gradual encroachment of the sea upon the land. This last contact occurs southeast of El Paso, and north of it there is nothing to warrant the belief of a further extension of the lower Cretaceous in that direction. Similar conditions exist south of the Diabolos and in southern Arizona.

With the beginning of upper Cretaceous time the sea became shallower along the coastal plain and in the western portion of our Texan area, and it was practically shut out from the great interior region of the continent during the period in which the non-marine Dakota sands were being deposited there. Similar sands, apparently the equivalent of these in time, but of marine origin, are found outcropping in the northeastern portion of the State, but they thin out and finally disappear before reaching the Brazos river. They have been called the Lower Cross Timber or Wood-

bine sands. These sands are not found again until we reach the extreme western portion of the State, and there the exposures are limited.

Over the greater part of our area the formation found in contact with the Vola or Buda limestone, the upper bed of the lower Cretaceous, is that of the clays and shales known as the Eagle Ford or Benton and which also overlies the Woodbine or Dakota when this is present.

During the interim between the deposition of the Buda limestone and the Eagle Ford shale the former must have stood very near the surface of the water, since even where long contacts are observable the two formations appear to be entirely conformable and there is little or no evidence of erosion in the limestone prior to the laying down of the shale.

The Benton shale marks the beginning of marine sedimentation of vast geographical extent, reaching from Canada southward into Mexico. There are at present, however, no remnants of this sedimentation within the central basin region of Texas, and if at any time either this shale or succeeding beds of the Cretaceous mantled this area, they have been completely eroded and no trace left behind. In my opinion, the indications are that after the emergence at the end of the lower Cretaceous the waters of the sea or ocean never again invaded this area, but that the connection of the marine waters of the Mexican region with those of the Interior Basin lay elsewhere.

The relation of the Woodbine sands to the Eagle Ford shale is such as to suggest that the former are simply the early shore deposits of the period and possibly contemporaneous with the basal portion of the shales lying to the south, which, with the deepening of the water northward, gradually covered them also.

These shales, therefore, are found as a fringe around the coastal slope and extending westward nearly to El Paso. Beginning at Red river, we have a thickness of 600 feet of clays, largely bituminous but with some lime, especially toward the top. Going southwestward toward the Colorado, they gradually thin out, the more limy portion only persisting so that at Austin the entire thickness is only some 50 feet. To the south and west, however, they again gradually increase in thickness, retaining their more limy character, and in the neighborhood of the Rio Grande in El Paso county are at least 1000 feet in thickness. Still greater thicknesses are reported in the Mexican area.

The Austin chalk, which followed, marked a change in marine conditions over the greater portion of our coastal plain. Only in the northeastern border and in the region west of the Chisos mountains in the trans-Pecos did the conditions remain as they had been, so that the deposits in these localities are similar to the Eagle Ford in character, although they carry the fauna of the chalk. For hundreds of miles between these localities, on the other hand, the white or creamy chalk abruptly replaces the clays and limy shales, indicating a deeper sea and one comparatively free from sediments derived from land areas.

The hundreds of feet of this formation are made up of chalk and chalky marls, but toward the end of the period more and more terrigenous sediments were incorporated with these, and they gradually pass upward into the Taylor marls, there becoming simply limy clays with some sand, and finally into the more sandy beds of the Navarro and Escondido which form the top of our upper Cretaceous series.

Thus the upper Cretaceous series as a whole indicates that

along our coast the sea gradually deepened and then as gradually shallowed toward the close. The total thickness of these beds in eastern Texas is estimated at 3500 feet. On the Colorado it is only 1500 feet, while toward the Rio Grande and in trans-Pecos Texas it again thickens to several thousand feet.

These deposits, extensive as they are, are really very small beside those which were laid down during the same period in the great interior region. Nor do they compare in thickness with those laid down as their southern extension in Mexico. Akin to each, they yet differ in many respects and especially in the variety of their fossil contents.

During the upper Cretaceous igneous forces again became active and in the vicinity of Austin one or more volcanoes broke forth and the ash from them is found interbedded with the upper portion of the Chalk and the lower portion of the Taylor marls. The old necks or plugs of basalt of these volcanoes are still to be seen southwest of Austin.

Many other bodies of basalt, which are probably of this same age, are found coming up through the beds of Cretaceous materials at various points between the Colorado and the Rio Grande.

The indications are that these igneous forces were still more active in the trans-Pecos country, and that the action was of longer continuance, either stretching well into the Tertiary or recurring during Tertiary time.

With the close of the Cretaceous period the recession of the sea brought to light a still broader area of our coastal plain and added it to the continental land, and over the greater portion of the State as it existed at the close of the Cretaceous land conditions have apparently continued almost without interruption until the present time.

In the northwest deposits of later Tertiary age occur in old lake or river basins, and similar deposits occur in connection with drainage channels in other portions of the State. In the trans-Pecos beds of clays and sands occur interbedded with volcanic materials which are probably of Tertiary age. Otherwise these Cretaceous deposits were not again inundated by marine waters until the Lafayette invasion of the late Pliocene, and this evidently covered them only in part.

That portion of our present area which we owe to Tertiary deposition forms a broad belt between the old Cretaceous land and the present Gulf shore. In it we find our greatest deposits of iron ores and lignites, of gas and oil, sulphur and salt.

A study of these Tertiary beds indicates that they were laid down, under conditions somewhat similar to those existing to-day along our coast, either in the waters of the Gulf itself or in the bays and lagoons which fringe it. We also find that while deposition was apparently regular during lower and middle Eocene time, it was either interrupted and irregular during the later Eocene, Oligocene, and lower Miocene, or that, if sediments were laid down during these periods, they were subsequently eroded, since, with some small exception, we find no evidence of them in this area now.

The Eocene as we know it is a continuation of beds of similar age in Louisiana and States lying to the eastward, and these continue southward beyond our boundaries into Mexico, finding their final outcrop in that region in the eastern borders of the Tamaulipas range which reaches the Gulf coast below Sota la Marina. South of that point they are not known in Mexico, although they, or beds with similar fossils, occur in Central and South America.

The basal deposits of our Eocene comprise clays carrying concretions of a bluish-gray limestone which weathers brown.

It is not always visible, however, for the overlying beds frequently overlap and conceal it.

The Lignitic beds which form the second stage of the Eocene are continuous from the Sabine to the Rio Grande, although on the latter stream they have largely lost their lignite-bearing character. These lignites, with the accompanying thinly bedded sands and clays, were slowly deposited in the quiet waters of coastal lagoons, and the lignite beds, while attaining a thickness of many feet in places, are usually of lenticular shape, although they may underlie a very considerable area.

These beds are best developed in the eastern portion of the State, extending southwestward to the Brazos river. They have a thickness of 1200 feet.

With the close of the Lignitic the lagunal conditions gave place to marine, and the succeeding stage was ushered in by the deposition of a belt of sands which, while of no great thickness in the eastern part of the State, increase in importance toward the Rio Grande, where they assume great prominence in the formation. These are called the Carrizo sands, and at times they cover all the older Tertiary beds and some of the Cretaceous as well. Just south of the Rio Grande they make up the body of a considerable range of hills.

These sands are succeeded by sands and clays with greensand which carry many molluscan fossils and constitute a very important member of the Eocene, extending entirely across the State. These are known as the Marine beds and have a thickness of 1000 feet or more. In northeastern Texas they carry also vast quantities of limonite iron ores.

Toward the close of this substage lagunal conditions again prevailed, and the Yegua clays with their accompanying lignites were laid down. This series of beds, with a thickness

of 600 to 1200 feet, is preëminently the gas belt of the coastal country. All of the large wells so far struck in that region derive their supply from it.

The Yegua was succeeded by another series of sands and clays, the sands greatly predominating, which we know as the Fayette sands. Where these sands are indurated, as they frequently are, they form ridges and hills and are the deciding factor in the topography of the area.

They were succeeded by another belt of clays and clayey sands which we call the Frio clays, and with these the deposition of the Middle Eocene was closed and the withdrawal of the sea left the entire Eocene a dry land area.

A careful study of this area has yielded no evidence, except in the eastern portion of the State, of any other beds having been laid down in it prior to those of the upper Miocene.

Between the Sabine and Neches rivers, however, erosion completely removed the Frio clays and all of the Fayette except a few remnants near Lufkin, and on the beds of the underlying Yegua thus exposed were laid down the clays and impure limestones of the Jackson or upper Eocene. These beds have been traced from the Sabine to a point some 20 miles west of Corrigan, where they feather out and disappear entirely and the Fayette comes in again in its proper position.

With the Jackson all deposition along our coast seems to have ceased for a long period. To the east in Louisiana and to the south in Mexico deposits of Oligocene age occur, those of Mexico being very extensive, but none of these are found in Texas, at least upon the surface. Similarly, all deposits of lower Miocene seem lacking.

Our next records date from the middle or upper Miocene. In the northeastern portion of the State, over what is now

known as the Staked Plain, a lake condition developed which continued in some shape through the Pliocene and into the Pleistocene. The different stages are well marked by characteristic vertebrate remains. The exact extent of this lake and its fluvial accompaniments cannot now be told, but at one time it evidently reached as far south as the lower edge of the Plain, and a portion of its eastern shore line is well preserved in the detached butte on the southern edge of Garza county.

Similarly, the Oakville beds which we find succeeding the coastal Tertiary deposits already described carry a vertebrate fauna of middle or upper Miocene age. On the Nueces river, where these beds have been most studied, the Oakville and overlying Lapara of the Pliocene are evidently deposits laid down in rapid currents of shallow water and consist principally of sands and sandy clays. These are succeeded by the Lagarto clays, which are highly calcareous, and these by the Reynosa phase of the Lafayette formation.

In this immediate vicinity the Oakville rests upon the Frio clays, as it also does on the Rio Grande; but in many places, either from the erosion of the clays or the transgression of the Oakville beds, these sands rest directly upon the Fayette, and so close is the resemblance of the materials of the Fayette and Oakville that in such case it is sometimes difficult to separate them.

East of the Colorado the Oakville is somewhat more conglomeritic in places and carries worn fragments of an upper Cretaceous gryphæa. It contains many fragmental remains of vertebrates and some beds of leaves.

In eastern Texas the Oakville is overlain by the Fleming clays, which are supposed to be the continuation, or at least the time equivalent, of the Lagarto, which they greatly resemble in character. These clays carry an extensive inver-

tebrate fauna of brackish water forms, the age of which is placed as early Pliocene. These fossils, found in connection with the outcropping of the beds 80 to 100 miles from the coast, are also found at a depth of 3000 feet in a well drilled near Terry, fifty miles south of their southern boundary.

Within the area occupied by the Fleming clays vertebrate remains have been found which belong to the upper Miocene. The difference of age as indicated by the vertebrate and invertebrate forms requires further investigation.

Up to this time no surface exposures of Miocene deposits of marine origin have been discovered in Texas, but they have been found in wells drilled at Galveston and Saratoga, and doubtless occur at other localities.

The Fleming clays are overlain by the Orange Sand phase of the Lafayette, which marks the close of Tertiary deposition.

Between the outcrop of these Lafayette beds and the Gulf coast there is a belt some fifty miles in width occupied by the Coast clays, which forms the latest contribution of the receding waters to our growing land.

These clays now form a comparatively level plain with a very gentle coastward slope. From data accumulating through a closer study of the region, and through the logs of wells drilled in the search for oil and water, we are gradually acquiring a knowledge of the conditions of the old Tertiary land surface on which these clays were laid down; and it now appears that this must have had a somewhat rugged topography, since, while these clays have a thickness of hundreds and even thousands of feet, in a few instances they fail to cover the tops of old Tertiary hills which to-day protrude through them. Others which are covered have been found

by drilling. It is in connection with such hills that many of the deposits of oil, salt, and sulphur have been found.

Thus, beginning with the granite core of the Llano-El Paso belt—the old Llanoria land of the paleogeographers—connection was gradually made during Paleozoic time with other land areas to the north and northwest. During the Eozoic the growth was southward and eastward in the waters of the Gulf or Ocean, which, upon the whole, now shows a recession of nearly two hundred miles from the early Cretaceous shore-line.

The entire area, since its emergence from the waters, has been subject to orogenic movements and to agencies of erosion, and these have sculptured the face of our land into the form in which we find it to-day.

II

INDIVIDUALITY

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We have reviewed briefly the manner in which the Texan area became a part of the continent by growth through workings of natural forces of sea and land. These, while operating in somewhat different ways to the north, the west, and the south, builded steadily to the completion and unifying of the whole.

This region, therefore, is, as we have seen, the meeting-place of three distinct provinces of geologic growth; and while there is a general uniformity in the deposits of the eastern and southern portions of the State with the coastal deposits of the other Gulf States, a similar uniformity of those of the northern portion with the great Central Basin region, and of the western portion with those of Mexico, New Mexico, and Arizona, there are also differences which, in their way, are as marked as the resemblances. These individualities are found not only in the character and extent of the deposits themselves, or the entire absence of deposits of certain periods, but also to a somewhat less extent in their present conditions as related to our use of them.

The pre-Cambrian rocks of the Diabolo region include a belt of limestones containing chert, and are more or less metamorphosed, some of them being marbles of pleasing color and texture. From their general character and stratigraphic position we have regarded them as the possible equivalents of the similar group of magnesian limestones in the Llano region called by Comstock the Texan marbles.

These limestones, which, in the Diabolos, seem to have a thickness of 500 feet, underlie a brown sandstone 150 feet in

thickness, above which we find red eruptives—porphyry, basalt, and lava—200 feet thick. Pebbles and boulders of the eruptives, brown sandstone, and limestones are found in the basal conglomerate of the Cambrian of this region, showing that these rocks are all pre-Cambrian.

This brown sandstone and the overlying eruptives, therefore, bear a relation to the Cambrian deposits of the Diabolo mountains similar to that the Llanoria quartzite and overlying rhyolite porphyry of the Franklin mountains bear to the Cambrian of that area. There is the difference, however, that at some points in the Diabolos there seem to be evidences of other beds having existed between the eruptives and the conglomerate.

Underlying these limestones there appears in many places a massive body of even-grained red material called by Streeruwitz the Diabolo sandstone. It is also found in similar relation to the Texan marbles west of this locality in the valley between Eagle Flat Mountain and the scarp of the Diabolo mountains to the north, and in various exposures where the Texan marbles are absent, from erosion or non-deposition, the Cambrian, Silurian, or Pennsylvanian rocks are found in contact with it. This material forms the country rock of the Hazel mine, and exposures of it in the hills north of the mine show a thickness of 500 feet, and the base is not visible.

As we have seen, the earliest evidence of the Cambrian sea in Texas is found in the Franklin mountains near El Paso, and its waters did not reach the Llano region until a somewhat later period.

If we compare the early history of the Llano region with that of the Arbuckle and Wichita mountains, which, although some three hundred miles north, are the nearest points outside the State where the earlier formations occur

as surface rocks, we find a close similarity in the initial sediments of the two areas. The basal series of the Llano region, beginning with the Hickory sandstone and followed by greensands, shales, and shaly limestones, finds its duplicate and probable continuation in the Reagan sandstone of the Arbuckles, not only in the character of the materials, but in fossil contents.

The broad extent of the Cambrian sea, which embraced the trans-Pecos, Llano, and Arbuckle regions, is shown by Ulrich, who states: "Very similar, apparently contemporaneous, deposits and faunas are found also in New Mexico, Arizona, and the Bighorn mountains of Wyoming."

The beds of shaly and massive limestone or dolomite with chert of the Llano region which follow this Cambrian sandstone and show continuous sedimentation through the uppermost Cambrian and into the lower Ordovician, are also found in the Arbuckles, overlying the Reagan sandstones as the Arbuckle limestone. Here, however, the maximum thickness of 1000 feet, which the beds attain in the Llano region, is greatly increased, reaching 4000 and even 6000 feet.

At this point deposition in both areas seems to have ceased for a time, and with the emergence of this limestone as a land area the history of the two regions ceases to be the same.

In the Arbuckles, after a brief period of erosion, the land was again submerged, and deposition continued more or less regularly through the Ordovician, Silurian, and Devonian into the Mississippian, and during this time some 3500 feet of sediments were laid down, no representatives of which are now known in the Llano region. Just how far southward the seas in which these materials were deposited in the Arbuckle region may have extended, cannot now be even surmised, but apparently they did not reach the Llano region,

which stood through all these ages as the barrier between these waters and those of the southern ocean. Or if any portion of the overlying rocks of the Arbuckle section was deposited in this area also, they were so completely eroded prior to the deposition of the Bend as to have left no trace of their existence.

With the close of the Mississippian came an elevation of the Arbuckle region, which then became a land area, and it does not appear to have been again entirely submerged at any time. In the early Pennsylvanian sea, which follows and which surrounded but did not cover these areas, we again find similar conditions prevailing in the vicinity of Llano and the Arbuckles and extending eastward into Arkansas.

In these waters were laid down the shales and limestones known as the Bend series in Texas, the Caney shales in Oklahoma, and the Fayetteville beds in Arkansas. Both in Llano and the Arbuckles these beds were laid down as a fringe around the land mass, and the fossils are the same throughout the extent of the beds. This condition was, however, comparatively short-lived, and with the close of deposition of the Caney shales in the north and the Bend in the south another uplift occurred which still further extended the land area and raised the Lampasas geanticlinal, running northeastward from the Llano region toward Red river, with a sea to the westward and land to the east.

In that portion of Texas east of this geanticlinal there has not yet been found the record of any deposits of earlier age than the Cretaceous, and the evidence from wells along the western border of the area proves that the Cretaceous rests upon a somewhat eroded surface of Bend materials.

To the northward in Arkansas, however, deposits were laid down both of earlier and of later age than the Caney-Fayetteville beds, and beds 15,000 to 20,000 feet in thick-

ness are found, the materials of which are thought to have been derived from a land area lying to the south that must have covered a large part of east Texas.

The Coal Measure deposits of central Texas, which accumulated in the sea west of the Lampasas uplift, also argue a land mass in this area persisting, probably, through the Pennsylvanian, but of its character and extent nothing can now be told. While it must have been of considerable size to have supplied the materials which are supposed to have been derived from it, it had, apparently, practically disappeared prior to the incursion of the Cretaceous sea.

Toward the close of the Pennsylvanian the beds of the Coal Measures east of Henrietta were, in some part, added to the land area, causing a shallowing of the sea in the Red river region; and in these waters and on the land thus formed on the east and north there appeared a new and curious vertebrate fauna which marked a distinct advance in the life history of the globe. The earliest evidences we have of these animals are the bones found in the clays, limestones, and sands deposited at this time, which now form the surface materials of Wichita, Archer, Baylor, and adjoining counties, and which we call the Wichita and Clear Fork beds. They were brought into notice first by the studies of Professor Cope, and our knowledge of them has since been greatly enlarged by later extensive collections and study by other paleontologists. So abundant are they, and so well preserved, that the entire skeletons of several varieties of them are now fully known, and we are able to reproduce their forms with accuracy.

They include peculiar and highly characteristic forms of amphibians and some of the earliest known forms of reptilian life.

The study of these remains by the paleontologists has

done much to show "the ways in which the evolution of the reptiles from the amphibians has occurred; to discover archaic forms that, one by one, bridge over the class differences between the amphibians and the reptiles; . . . but we have, nevertheless, not yet found a creature about which there is doubt as to its position" in one or the other of these classes.

In addition to these animals we find, preserved in the clays, the remains of many plants which flourished upon the land surface to the east and north; and these, too, show the decided change which took place immediately following the close of the Coal Measures by the introduction of many new and distinctive forms to take the place of other forms abundant in the preceding period, but which disappeared at or soon after its close.

Furthermore, in some of the limestone layers of these beds in Wichita county we find among marine invertebrate forms, which have persisted from Coal-Measure times into this, certain forms of ammonites which are characteristic of the Permian elsewhere, but which, strange to say, have not yet been discovered further to the south in beds of the same age which are the direct continuation of these. One of these ammonites is one of the few forms found in this region which were also found in the Guadalupean deposits.

This shallowing of the sea in the northern part of our area does not seem to have materially affected the depth of the waters farther south, since, as we trace the individual strata of the clays and sands in that direction, they become more limy, passing at length into limestones and clays. In the southern extension of this sea, as now shown by rock exposures through Shackleford, Callahan, and Coleman counties, the deposits themselves indicate a somewhat deeper sea than that in which the Coal Measures were laid down,

but otherwise very similar conditions of sedimentation; and this is further emphasized by the invertebrate fossils found in them, which indicate that the forms of the Pennsylvanian persisted into these Permian beds (which constitute the Albany phase of the Wichita) without very marked change. So little difference is there between the fossils of this Albany limestone and those of the underlying beds of the Cisco that for a long time many considered it a part of the Coal Measures, and even in their northern extension Dr. White, who first discovered certain characteristic Permian ammonites in the Wichita beds, called attention to the essentially Coal-Measure character of the accompanying fossils. Only a few species were found which mark the advance, probably no more than have arisen during similar intervals between two stages of the underlying Coal Measures.

This condition of only a slight change in the marine invertebrate fauna shows a marked difference from the life development of the land area immediately adjacent to it and of the same identical period, where, as we have seen, we have a well-developed Permian flora and vertebrate fauna; and it shows even greater differences from the marine fossils of the Guadalupe mountains, also of identical age, lying west of it, where open sea conditions at this same time permitted the coming in of an extensive invertebrate fauna of different species and of a decidedly later facies.

The discovery of the Guadalupean fauna was made by Dr. Shumard, over fifty years ago, while making examinations for artesian water in west Texas and New Mexico, under Captain Pope. His collections were made from the south end of the Guadalupe mountains, where the peak of white limestone known as El Capitan lifts its head 8500 feet above sea-level and reaches the greatest elevation known in our Texan area. Later examinations of these mountains

and the Delawares, which are their continuation to the south, were made by other geologists, and the Guadalupean fauna has been studied and described by Girty, who states that it has a very individual character among known faunas, though it is probably related to several. After comparison with similar faunas of other regions, he decides that in all of these there is none with which the Guadalupean can really be considered closely allied, the nearest probably being those of the Salt Range and Himalayas in India and of the Fusulina limestone of Palermo in Sicily. He also states that while such differences might be expected from their widely separated geographic positions, greater freedom of migration, and their environment, he thinks it surprising to find the Guadalupean fauna so completely different from anything known in the Mississippi valley, whose geographic position is relatively so close. It is no longer so when surrounding conditions are known.

These three phases, which approximately occupy the same time interval and show in such different degree the development of life which is supposed to mark the change between the Carboniferous and the Permian, illustrate a feature of geologic history which may at times be of great importance.

The open land to the north and east and the open sea to the southwest gave free entrance to the new forms of vertebrates and plants, on the one side, and the new forms of invertebrates, on the other, while in the enclosed waters of the interior sea, largely cut off from outside influence, the old fauna continued to exist with little change.

From these conditions it can be clearly seen that however and wherever these changes in land and sea fauna that mark the advancing periods may have taken place, they were not always manifested in the same region simultaneously, but when conditions were unfavorable for such simultaneous in-

cursion there may have been overlapping, one way or another, of the land fauna or flora of one period and the marine fauna of another.

The history of our Triassic time is somewhat obscure, but it is apparent that during its continuance the greater portion of the State was above the sea and subjected to extensive erosion. Our only records are found in the old basin which existed in the Staked Plain region and which may have been inherited from the closing period of the Permian. The extent of this basin is not known, but we find that it underlay the entire area of the Staked Plain; that it extended southeastward to and beyond the Double mountains of Stonewall county, and to the north and west of the Plain into Oklahoma and New Mexico, so that the probability is that the portion within our area formed the southern extremity of a basin reaching far to the north and northwestward.

These deposits, which Cummins called the Dockum beds, are composed of sandstones, conglomerates, and clays, and the fossils show that it was a fresh-water inland basin. In them we find the fragmentary remains of batrachians and reptiles, including crocodiles and dinosaurs, which are similar to those of the same age found in the Great Basin region to the north; and along the eastern border of the lake we find banks of fossil shells of the *Unio,* of which four species have been described from one locality. These are of special interest, as has been previously stated, because of the fact that they are the earliest known forms of these fresh-water mollusks.

The Texas Cretaceous, taken as a whole, has an individuality which separates it in a measure from the Mexican deposits on the one hand, and those of the Gulf States on the other. From the latter it differs in the fact that the lower Cretaceous of Texas shows an extensive series of marine

deposits, while the beds of similar age to the east are those of fresh water, and even in the upper Cretaceous approximate identity of faunal contents is only reached toward the top of the series. From the Mexican deposits, on the other hand, it differs in a section which is apparently less complete, of a greatly diminished thickness, and seemingly of deposits of more nearly marginal character. There are also marked variations in the fossils.

It shows, moreover, certain differences within our own borders which are of greatest interest to us, and it is of these that principal mention will be made at this time.

In any general consideration of the Cretaceous deposits of the State one must bear in mind the important fact that in the greatly extended area over which this formation occurs we naturally expect variation of conditions of sedimentation and consequent differences in the sediments themselves.

If we draw a line from El Paso to a point on Red river north of Montague and follow the river to the eastern border of the State, we mark the northern boundary of all our Cretaceous deposits except those underlying the Llano Estacado. The latitudinal extent of the formation thus marked out is over 700 miles.

The exposures south of this line occupy an area roughly crescentic, the greatest width of which is 350 miles.

The eastern extension of this line on Red river and the western on the Rio Grande at El Paso are the regions of littoral sediments, while the deposits of the demilune to the south—the direction from which the sea encroached upon the land—are those of deeper waters.

Therefore the deposits of the two extremities are sands, clays, marls, and somewhat meager limestones which, as we go southward, gradually pass into clays, shales, and heavy limestones. This fact is apparent with the greater number

of the subdivisions of the Cretaceous, beginning with the Trinity.

It is quite certain that the basal Trinity sands do not reach Red river, but that the sands found there are Paluxy. Similarly, the Trinity is not known on the Rio Grande closer than fifty miles from El Paso. This indicates that land conditions persisted in these localities through a part or all of the Trinity, and the deposits which follow show that they were not submerged as deeply as the more southern territory.

The long period elapsing between the emergence of our region at the end of the Permian, extending as it did through the entire Triassic and Jurassic, gave time for great erosive action over the land surface, and this resulted, so far as can now be seen, in a fairly complete base-leveling of the greater part of the old Carboniferous land prior to the incursion of the Cretaceous sea.

This base-leveling facilitated the encroachment of the water so that the Trinity sea probably covered the land, relatively, with considerable rapidity. The gradual extension of the waters to the north and the deepening of the sea to the south is beautifully told in the sediments exposed along the Colorado river on the eastern border of the Llano region.

The erosion of the Colorado and its affluents has channeled through the entire thickness of the early Cretaceous beds, clearly showing the basal sands of the Trinity with the overlying arenaceous limestones of the Glen Rose. These attain their maximum thickness north of Austin, thinning toward the northwest, and by following the outcrops of the various beds of limestone in that direction we find that they finger out into the underlying sands, showing that they are but deposits in the deeper waters of the sea of which some portion of the Trinity sands are the contemporaneous lit-

toral sediments. Just as the Trinity grades upward, imperceptibly, into the Glen Rose, so do these limestones, in turn, grade upward into the sands of the Paluxy, where it is present, so that at many localities there is no apparent sedimentary break between them.

The thinning of the beds continues to the north and west of the Llano region until the Glen Rose beds entirely disappear and the Paluxy sands are directly superposed upon the Trinity, while further north it is probable that the Trinity itself is entirely lacking and that the basal sands, if present, represent only the Paluxy or even some later stage.

Page calls attention to the fact that the entire Trinity is missing at several places in Burnet county, apparently through non-deposition, and that the Walnut clays and Comanche Peak limestone directly overlie the Ordovician limestone. Thus the 500 feet of Trinity and Glen Rose sediments which are exposed in the Colorado near the Burnet-Travis county line thins out entirely in the distance of 25 miles, due to the fact that parts of the land at the more northern locality, even at that date, stood too high for the sea to engulf them.

On the southern border of the Llano region this condition is even more noticeable than on the eastern, for there the granite peaks more clearly show the conditions of deposition that surrounded but did not cover them during the Trinity and Fredericksburg periods.

Other detached areas lying some distance to the southeast of Burnet were similarly too high and formed islands in the Trinity sea, but these were covered by the succeeding Comanche Peak sediments. Several such have been found in drilling for artesian water.

The absence of the Trinity has also been noted in some of the buttes lying east of the Staked Plain.

Such uncovered areas, however interesting they may be geologically, form so small a percentage of the great surface covered by this mantle of sand east of the Pecos as to be practically negligible when we study its economic value as the source of so large a portion of our artesian water.

The Rio Grande discloses conditions somewhat similar to those between the Colorado and Red river. Exposures in or near the river valley in the vicinity of the Chinati, Quitman, and Malone mountains show the basal sands and overlying Glen Rose limestones in strong development. In the vicinity of Presidio the basal sands seem to have a thickness of 400 feet and the Glen Rose 700, while on the south slope of the Quitmans there is a series of sandstones and silicious limestones apparently of great thickness underlying the beds referable to the Glen Rose and which are here 900 feet thick or even more.

To the northward, across the railroad, these beds show a greatly diminished thickness, soon thin out entirely and are overlapped by later deposits. The most northerly and westerly occurrences known are those of the ridges just north of Sierra Blanca, Flat Mesa, and the Finlay mountains.

The Fredericksburg also presents different facies in different localities. In its typical development it comprises three members—the Walnut clays, the Comanche Peak beds, and the Edwards limestone. These three divisions are clearly recognizable over a very large area east of the Pecos, including the line of buttes which form the Callahan divide and the outcrops south of the Llano region.

Throughout a large portion of this area the Edwards limestone consists of deposits laid down in clear water of some depth, far enough from shore to escape the admixture of terrigenous sediments. In the region of shallower water

along Red river it shows an increase of coastal debris, and many of the fossil forms characteristic of its purer phase do not occur in it. It is in fact no longer separable from the underlying Comanche Peak beds, and the two are, therefore, considered as the Goodland limestone, which at its best attains a thickness of only a few feet.

Going southwestward from Austin toward the Pecos and trans-Pecos region—a region which was covered with deeper waters for a long period of time—we find that the Comanche Peak marls gradually change to limestone and the Walnut clays to marls and limestones, both finally coalescing with the overlying Edwards so that there is no longer any lithological difference between them. In such case their presence can be known only through distinguishing fossils. In this manner, due entirely to different conditions of deposition, we have in places the limestones of the Fredericksburg resting directly upon the Trinity.

Still further west in the Rio Grande region we find, on the contrary, thin beds of sandstone coming in and separating these beds of limestone, and to the northward across the railroad lines the sandstones thus occurring become thicker and the limestones are also silicious, indicating that the deposits were laid down nearer a shore-line.

It is, therefore, apparent that in this immediate area the shore-line of the Cretaceous sea maintained an approximately constant position from early Trinity time to well through the Fredericksburg. This line was probably not more than 50 to 60 miles southeast of El Paso. That the sea did not include El Paso during this period is shown by the absence of deposits there which can be referred to it.

Between the Finlay-Sierra Blanca region and El Paso later deposits cover and conceal any extensions of the Cretaceous beds that may exist, and the next exposures to be seen

are the basal beds of limestone of the Muleros mountains. These seem to represent practically the top of the Fredericksburg, and show only a small development (70 feet) beneath the overlying marls in which Washita forms appear.

Here again, as noted in the Red river section, in the beds referred to the Fredericksburg we miss the characteristic fossils of the Edwards limestone, and find instead an assemblage of forms which more nearly resemble those of the Goodland limestone.

Similarly, too, the deposits referable to this division in these two regions of shallow water exhibit only a small portion of the thickness attained by the beds in the off-shore areas.

The Fredericksburg, with its extensive development of deep sea limestones and comparative poverty of shallow water sediments, was followed by the Washita, in which these conditions are largely reversed. It is in the littoral regions of Red river and El Paso that the deposits of the Washita show their widest differentiation and greatest thickness, while in the deep sea area they are less variable and in most cases of less thickness. In its simplest expression the Washita is composed of a basal limestone, the Washita or Georgetown, overlain by the *Exogyra arietina* or Del Rio clays and the Buda limestone. This is the section at Austin and south and westward to the trans-Pecos region.

Going northeastward from Austin toward Red river, the Buda limestone, which is 80 feet thick on the Colorado, gradually thins out, and beyond the Brazos it is no longer distinguishable even through its fossils, although it seemingly is found again north of Red river in Oklahoma.

The Del Rio clay, however, with a thickness of 80 feet at Austin, maintains a similar thickness to the Brazos, beyond which stream it is gradually expanded into a series

of shales, marls, sands, clays, and limestones known as the Denison beds, with a thickness of 200 feet at Denison.

Similarly, the Washita limestone, with a thickness of 80 feet at Austin, shows a separation into several members when followed northward.

In the Red river section the Kiamitia clays form the base followed by the marls and chalky limestones of the Duck creek beds, capped by the Fort Worth limestone, and these together show a thickness twice as great as the Georgetown limestone at Austin.

The fossils of these various subdivisions of the Washita are very numerous and characteristic. Many of them are seemingly confined to the nearer shore deposits of the northern border, but others are as wide-spread as the formation. By far the greater number and the greater variety of species found within the several beds of this division are those of the shallower water. In the deeper sea conditions were more stable and there were fewer changes of form—so little, in fact, that in the vicinity of Devil's river and further west certain aberrant forms which are characteristic of the Edwards limestone throughout its extent have persisted and are found in the Washita (Georgetown) limestone as well.

As has been stated, the section south of Austin is more regular than that to the north of the Colorado. The basal limestone shows a decrease in thickness in some places, and is so similar to the underlying Edwards that it can be distinguished from it only by the fossils that it carries. This is true as far west as the Chisos mountains and also near Sierra Blanca.

The Del Rio clays have often been mentioned as a formation of rather remarkable regularity for one of its composition. This distinctive clay bed is nearly always present in approximately the same thickness and is characterized by

its peculiar fossil, the *Exogyra arietina*. It carries numerous other forms, especially toward the top, but nothing like the number that are found in its northern development on Red river.

The Buda limestone also maintains a rather constant thickness and character throughout all this section.

In some parts of the trans-Pecos the Washita occupies a very prominent place among Cretaceous deposits, as it was during this period that the Cretaceous sea, which had been held back so successfully during the Trinity and most of Fredericksburg time, spread northward over the former land area lying east of the Guadalupes to and beyond the northwestern border of the State, overlapping the Fredericksburg and the Trinity, or, more probably, the Paluxy.

This is particularly well shown in the vicinity of Kent on the Texas and Pacific railroad. Here there is no Fredericksburg visible at the surface, and what is found in excavations is rather of the nature of the Goodland limestone phase. No Edwards limestone is known. South of the railroad track the Washita limestone is well developed, with great numbers of fossils. As we go northward we find the Paluxy sands underlying the Washita and successively higher and higher beds of the limestone coming down into direct contact with it. The Washita materials are not found overlying the other Cretaceous of the Llano Estacado, but the section of Tucumcari mountain shows, directly overlying the Triassic, beds of the Washita with fossils similar to those at Kent. Consequently, it is very probable that it did cover the plains at some time. At Kent the clays of the *arietina* have not been observed, although they are found in their regular position at points south.

The Buda limestone, however, does occur with its usual fossils.

In the Big Bend of the Rio Grande, including Presidio, Brewster and adjoining counties, the exact line of separation between the Washita limestone and that of the Fredericksburg is difficult to find, owing to the great similarity of the two. The Washita becomes softer and more shaly toward the top and can be recognized through its fossils. Its thickness in the region adjacent to the Rio Grande is variable, just as is that of the Fredericksburg, and, like it also, it at times far exceeds anything that is known further north and east.

The Del Rio clays are usually present, although the *Exogyra arietina* is not always to be found in them. The Buda forms the capping stratum, as usual.

Going northward from the river, the Washita becomes more marly in character, as has been noted in the Kent section. West of Sierra Blanca the Washita only occurs in remnantal patches which show sandy shales and sandy limestones with fossils of this period, with a total thickness for the entire division of not much over 100 feet. Here, in its more northern exposures, it overlaps the Fredericksburg and is imposed directly upon the Carboniferous.

The difference in the conditions which existed in the eastern and western portions of our area is shown by the variations in the horizons of certain fossils occurring in them. In the Red river region the little *Exogyra plexa* is found in the Kiamitia clay, corresponding to the lower part of the Washita limestone. At Kent and further west it occurs either at the top of the Washita limestone or in the Del Rio clay. On the other hand, the *Nodosaria texana,* which throughout the east is confined to the Del Rio clays, is found in the Sierra Blanca-Malone region in the Washita limestone and Fredericksburg as well.

In the Muleros mountains we find a development of the

Washita which differs in many particulars from that of other portions of the trans-Pecos, and, while possessing features distinctly its own, is more nearly similar to the Red river section.

Beginning at the base, there is a band of clays and clayey limestones followed by ledges of harder limestones and overlain by a considerable thickness of clay shales with indurated limy bands, the fossils of which seem to show a close relationship with the Preston beds of the Red river section. These beds and their fossils, taken in connection with the underlying limestone, give a section which, in its assemblage and distribution of fossils, shows a close resemblance to that on Red river including the Goodland limestone, Kiamitia clays and Duck creek beds.

Succeeding these are flaggy argillaceous limestones with marls and shale partings a hundred feet in thickness, which are, stratigraphically and in a general way, the faunal correlatives of the Fort Worth limestone.

Following this, the Del Rio clay is here represented by brown sandy calcareous layers passing upward into clay shales and lime bands alternating with sandy flags containing both *Exogyra arietina* and *Exogyra plexa* as well as other Del Rio fossils. These beds are in turn capped by red, gray or white sands varying in thickness from 60 to 300 feet.

This massive sandstone is followed by clay shales with bands of limestone nodules, passing gradually into a hard limestone. This carries the fossils of the Buda limestone, including *Hemiaster calvini.*

The entire thickness of the Washita section in the Muleros mountains is 600 feet or over—fully 200 feet more than the Red river section. This difference is fully accounted for in the body of massive sandstone which is found here between the Del Rio clay and the Buda limestone, the only

occurrence of the kind known within our entire area. The only similar occurrence which is now known is the sandstone which occurs at the top of Washita deposits in Tucumcari mountain. A peculiarity of the sand at Muleros is the number of large shells of the *Exogyra clarkii* which are found in it and which continue upward through the overlying marls and limestones of the Buda.

The earliest deposition of the upper Cretaceous consists of the sands of the Dakota or Woodbine series, which are found in Texas in both littoral zones. On the east they form a sandy belt known as the Lower Cross Timbers, extending from Red river to the Brazos at Waco. In the west they are found in the Muleros section and in one or two outlying exposures, such as that at Eagle Flat, 20 miles east of Sierra Blanca. The time relation of these marine deposits to the brackish or fresh water beds of the interior is proved by the identity of the fossil flora found in both, in addition to which our beds both east and west carry a marine fauna which is distinct from that of the lower Cretaceous. As has been previously stated, the Dakota is absent throughout the greater portion of our area, and the succeeding beds of clays and shales which we call the Eagle Ford, and which are stratigraphically and faunally the continuation of the Benton shales of the interior region, are the lowest member of the upper Cretaceous which we find.

From Red river southward the clayey members decrease and the limestones persist and increase in thickness until along the Rio Grande between Del Rio and Eagle Pass they are lime shales almost exclusively. In the Big Bend of the Rio Grande they are lime shales at the base, grading upward into marly clays, and in the Muleros section they consist of fine-grained sandstones, and shales with some silicious limestone.

Of all the upper Cretaceous deposits, the Eagle Ford seems to be the most uniform and constant. While it has its near shore phase of sands and clays, the bulk of the deposits are limy shales, and these not only encircle the Edwards plateau, but stretch southward into Mexico for two hundred miles or more, where they attain a very much greater thickness than anything we know in Texas. Furthermore, these deposits, wherever we find them, whether sands or clays or lime, are consistently shales and carry a characteristic fauna throughout their entire extent.

During the deposition of the Chalk a condition of clearer waters existed, and in the main the Chalk is fairly free from materials derived from the land area and is an almost pure chalk, but there are localities where the clays were carried out and deposited with it, occasionally to such an extent as to make it merely a chalky marl.

In its relation to the underlying Eagle Ford it shows the same variations noted in other similar contacts. In the eastern part of the State the division is quite clearly defined and the line of separation can be fairly well made out even on the Rio Grande east of Del Rio. To the south it is sharply defined, but to the west the distinction is not so readily apparent, and in the region of the Big Bend of the Rio Grande, where the Eagle Ford takes on a more marly character and the Austin chalk is marly also, it is difficult to find the dividing line without careful examination of the fossils.

The upper margin of the Chalk is not so well defined, since at most places it grades almost imperceptibly into the base of the overlying Taylor marls.

On the eastern border the Taylor marls and Navarro beds, as a whole, mark a period of gradually shallowing water, interrupted, however, in the northern part for a time

by conditions of deeper, clearer waters in which the Anona chalk was laid down.

On the Rio Grande border also we find in the region lying between Eagle Pass and Uvalde a very considerable variation of the deposits belonging to these formations. Along the river below old Fort Upson the representatives of the Taylor and Navarro are found for a distance of 40 miles and include various members not present further east.

The basal beds or Upson clays are marls similar to the more eastern deposits and carrying calcareous nodules which are septarian in form. These are followed by the San Miguel, a series of sandstones and clays with glauconite which passes upward into more calcareous strata, also glauconitic. Fossils are abundant throughout the entire series. Overlying this there are other sands and clays with beds of coal, one or more of which are workable. While the area of workable coal in Texas is not very great, the extension of these beds south of the Rio Grande in Mexico furnishes the principal Coal Measures of that republic.

The upper beds of the formation are sands and clays with bands of limestone, reefs of oyster shells, and many other fossils which are known as the Escondido beds. The entire series has a thickness of more than 2000 feet.

Going northeastward toward Uvalde from this extensive exposure along the river, these various beds gradually coalesce, and in the southeastern part of Kinney county we find them represented in the Anacacho mountain by a small thickness of the basal clay passing into the Anacacho limestone, which is covered by a comparatively small amount of the upper portion of the Escondido beds. These have here a total thickness of not more than 400 feet, and this is less than 30 miles from the river.

The Anacacho limestone is largely made up of broken shells and remains of sea organisms, and apparently represents in time and general character the Anona chalk of the eastern portion of the State.

The coal-bearing character of the Taylor marls is also exhibited in the Rio Grande valley around San Carlos in the northwestern portion of Presidio county. In this region the base of the section is composed of shales with lime concretions overlain by interbedded sands and sandstones which are more or less calcareous. Then follows a considerable thickness of coal shales with two beds of coal overlain by red and brown sands capped by a lava flow. Overlying the lava bed we find a conglomerate passing upward in sandstones of various colors interbedded with coal, calcareous clays, and volcanic ash. These beds have a thickness of over 2000 feet and are capped by the heavy lava flow which forms the rim rock of the Sierra Vieja.

It would appear from the data so far obtained that the coal of this region is somewhat lower in the section than is that at Eagle Pass.

We have in this region, therefore, conditions of coal formation which, in a measure, correspond with those of the Montana beds of the Interior Basin region, and which are the correlatives of these in age; but the fossils which are found in great abundance in both of the Texas regions, while in part similar to those of the Interior Basin region, are more nearly akin to those of the Ripley of the upper Cretaceous of the Gulf.

The occurrence of basalt and volcanic ash in connection with the Taylor marls in the Austin region, as well as in the far west at San Carlos, gives an idea of the wide-spread activity of the igneous forces which came into operation dur-

ing the close of the Cretaceous and must have continued well into the Tertiary.

What has already been stated regarding the Eocene deposits of our State gives in a general way their relations to and differences from beds of similar age in adjoining regions.

The Lignitic, which in the northeastern portion of the State carries such vast bodies of lignites, gradually loses these toward the southwest, and beyond the Guadalupe these features are practically absent.

The Queen City beds of the east, with a thickness of less than 100 feet, increase on the Rio Grande to several times that thickness, and the overlying Yegua and Fayette, the fossils from which are almost unknown in the east, carry a very plentiful fauna on the Rio Grande. Taken as a whole, however, the different substages are very constant in their composition and characteristics entirely across the State.

Of the later beds of the Tertiary there is little more that can be said. So recent has been their emergence from the sea, and so little have they been disturbed by erosion or earth movements, that it is difficult to get any real information of them, except what they themselves show upon their surface.

In the later Tertiary deposits, both of the Llano Estacado and of the Coastal Plain, we find remains of the abundant animal life of the period, most of which is now extinct or unknown on this continent.

Herds of mastodon and elephants of different species roamed over this area. Camels of various kinds, gigantic species of ox (*Bison latifrons*), of the sloth (*Megalonyx*), the armadillo (*Mylodon*), and land tortoise existed, together with peccaries, wolves, foxes, and many smaller ani-

mals. The saber-toothed tiger, a species of lion, and the rhinoceros are also found.

Horses, which appear to have become extinct before the discovery of the continent, are represented by numerous species ranging from the three-toed variety to an animal of immense size which is found in southwest Texas.

One of the most interesting chapters of our history would be that of the igneous rocks, but so little have they been studied up to this time that there is little that can be safely stated of them.

The basalts that accompanied the vulcanism of late Cretaceous time from Pilot Knob near Austin to Fort Inge have been mentioned, as also the beds of volcanic ash which are found intercalated in certain horizons of Tertiary rocks. It is in the trans-Pecos region, however, that these forces have their greatest manifestation, and here they have yet to be studied.

The peaks of Sierra Blanca are composed principally of igneous rocks, but we as yet know nothing of their history, nor are we sure of the age of the granites of the Quitman range.

In the Eagle mountains, however, we find great shafts of porphyry thrust skyward through rocks of upper Cretaceous age, and similar protrusions occur in many of the mountains to the southeast. In the Sierra Viejas a capping of basalt 300 feet in thickness was spread over the top of the upper Cretaceous beds before the great rift occurred which, in the vicinity of San Carlos, caused a dislocation of fully 2000 feet in the separated portions of these beds. In some places the basalts or porphyries, instead of reaching the surface, were thrust along the planes between beds of limestone or other material and are now found as sills in them, and at

others vast bodies of tuffs or volcanic ash are interbedded or commingled with the deposits.

In the Terlingua region three distinct periods of vulcanism were made out, each accompanied by characteristic eruptives, and their relative ages determined; but as to the actual time of their activity nothing could be determined save the fact that it was after the deposition of the lower Cretaceous, since these rocks were cut by them.

This branch of our history, therefore, like that of our more recent coastal land, must await more study before we can appreciate its full significance.

III

ECONOMIC FEATURES

THE various facts which have been observed and recorded regarding the geologic history of our State, and which have been briefly touched on here, show the manner in which it was brought into being, and in which the various formations were laid down, their relations to those of other regions and the character of life they evidence. These facts have a decided interest not only for scientists but for all thinking people. There is, however, still another phase of this geologic history which must also be of interest to every one, and that is the part which geologic processes have played in fitting the land for habitation, by preparing the soil and storing up water and fuel as well as in producing and preserving stores of valuable minerals for our use and comfort. This is the utilitarian side of geology, the value of which is coming to be more and more fully recognized.

The importance of a correct understanding of the geologic features of the region in this connection will be readily seen when we consider that practically all materials of economic value, such as ores, minerals, coals, oils, artesian water, etc., that occur within our borders, are found in some definite relation to one or the other of the various geologic formations that have been discussed; and any real investigation of these materials, looking toward their proper utilization, must take into consideration the fact and character of this relation and include the study of its geological significance.

It is my purpose here to enumerate the more important of

these materials as we now find them, and to indicate briefly the relations between them and the rocks with which they are associated.

Among the granites and associated rocks of pre-Cambrian age in the Llano region there are many varieties of stone which are well suited for building as well as for decorative and monumental uses. Besides the red or pink granite, of which the State capitol is built and which enters into the structure of many other buildings, both public and private, in various portions of the State, there are gray granites, serpentines of different colors, quartz porphyry, etc., many of which stones are susceptible of high polish and will, in time, be used extensively.

The Texan marbles will also furnish a limited supply of desirable ornamental stone, occurring as they do in beds of medium thickness, even-grained and fully compact in structure, and of a snowy whiteness.

It is in connection with this group of pre-Cambrian rocks also that the principal mineral deposits of this region are found.

There are legends of "lost mines" of fabulous value in the Llano region; but although many men have made determined efforts to find them, all search for them has been in vain. Among these was the Bowie mine, supposed by some to have been in the Honey Creek region in the southeastern part of Llano county, but held by others to be farther north and west.

The story, which was formerly believed in by some who were contemporaries of Bowie and who spent much time in a search for it, is, briefly, that somewhere in this region Colonel Bowie found a cave or an old Spanish working in which native silver occurred in such large quantity that it could be cut out with a hatchet, and that when he left it he concealed

the opening. As a result of this search, caves and old workings have been found, but no trace of the wonderful silver-mine has ever been discovered.

Some placer gold has been recovered from the sands along Honey and Sandy creeks south of Packsaddle mountain, which probably comes from the disintegration of some of these older rocks, and small quantities, probably having the same origin, are found in the sands of the Colorado river as far south as Austin.

Years of prospecting in this region have brought to light, in the pre-Cambrian mica-schist, a few quartz stringers which carry gold in small quantity, and in the granites and schists some small veins of galena carrying silver, and irregular deposits of copper glance carrying both gold and silver. Platinum is also reported, and some work has been done at the locality where it was found. Many others of these occurrences have been prospected, and on some of them shafts of considerable depth have been sunk, but up to the present no workable deposits of the precious metals have been commercially developed.

It is believed by some in this region that further work on the copper-silver deposits of the northwestern part of Llano county will yet result in the development of paying mines. These copper deposits are found in the Babyhead region and west of Pecan creek. Considerable areas are found in which the highly colored carbonates are spread over the surface, and a number of shallow pits and tunnels were dug on these many years ago. The ores found were the carbonates with some sulphides—erubescite, gray copper, and pyrite—but only one locality afforded ore enough even for a small shipment. At another locality a considerable amount of ore was found in prospecting, but no shipment was made

and no development has followed. It does not seem probable, therefore, that these ores occur in sufficient quantity to make mines of any considerable value.

The conditions in the trans-Pecos seem to have been more favorable, and workable ores of copper, lead, and zinc, principally silver-bearing, are found in connection with the granites of the Quitman mountains, the Hazel sandstone of the Diabolos, and the schists of other mountain ranges of the area. Some silicious gold ores are also found.

The Bonanza and Alice Ray mines in the Quitman mountains show veins of galena and blende which carry silver and some gold. These have produced some shipping ores and will probably become steady producers when conditions permit. There are many other prospects in these mountains, some of which appear to be well worthy of further investigation.

The Hazel mine in the Sierra Diabolos, north of Allamore, has produced a considerable amount of gray copper and copper glance carrying good values in silver, and similar ores are found in other less developed prospects in the same vicinity.

In the other ranges prospecting has developed good indication of ores in rocks of this period; and while little mining has been done, the prospects are that good mines may yet be opened in them.

The lack of development of these deposits of precious metals is no doubt largely due to our land and mining laws. In this State the owner of the land is owner of all minerals occurring under it. The trans-Pecos region is largely occupied by blocks surveyed under various railroad grants, in which one-half the land is under private ownership, leaving the alternate sections alone belonging to the State or to the

schools or asylums; and it is only such of these State, school, or asylum lands as have not already been disposed of, which can be granted under mining laws. These conditions render prospecting so risky as practically to prohibit it, since even if mineral be found, the chance of getting title to it is altogether too uncertain.

When the region is better settled and the land lines more certainly known, this condition will be remedied and these valuable deposits will be sought by owners or prospectors, and the development that will follow will add greatly to the wealth of the State.

The iron ores of the Llano region have been long known. They comprise magnetites and hematites with only a small measure of limonite. The magnetites occur in connection with the pre-Cambrian rocks. The hematites and limonites, probably derived from these, are connected for the most part with the succeeding sedimentary deposits.

The magnetites occur as large lenses or bosses and have been pretty thoroughly prospected and their area determined by drilling. Many of them are of excellent quality and will furnish a large quantity of high-grade ore for use in connection with the smelting of the brown ores of east Texas. The origin of these ores is not definitely known. If it should prove that they are derived from the alteration of sulphides, their excellent quality may not be found to continue downward as far as is now believed probable.

Similar iron ores are found in west Texas also, but no work has been done on them.

Deposits of workable manganese ores occur in the eastern portion of Mason county, where they were prospected years ago at what was known as the Spiller mine, but no mining has ever been attempted.

Traces of tin ore have also been found in the Llano re-

gion, and it was reported from this region by the Geological Survey. Later other parties found some stream tin in the eastern part of Mason county, in connection with crystals of topaz, but up to the present time no special work has been done on it.

In the Franklin mountains, however, 15 miles north of El Paso, tin ores occur in well-defined veins in connection with the granite, which is here supposed to be intrusive and later than the Cambrian beds.

Seven veins have been exposed by open cuts and are said to exhibit the usual characteristics of the tin beds of Cornwall. The surface values are good, a considerable area has been prospected, and some mining carried on. A small mill and reverberatory furnace were erected and several tons of very pure tin were made, when operations were temporarily suspended.

At Baringer hill, on the west bank of the Colorado river some 20 miles east of Llano, there occurs a deposit of rare-earth minerals which, so far as now known, is entirely unique, since at no other place have they ever been found in such large masses or in such quantities as here.

These minerals, which are valuable chiefly for their contents of rare-earths of the yttrium group, include gadolinite, fergusonite, allanite, and cyrtolite, with smaller quantities of a number of other species.

The hill was named for Mr. Baringer, who made the first discovery of gadolinite in 1887. It is not over 50 feet in height, is 100 feet or more in width, and between 200 and 300 feet in length, and owes its existence to the superior hardness of the pegmatite dike of which it is composed to the porphyritic granite into which it was intruded. In the center of the pegmatite there is a large mass of quartz, while at its outer edge, in contact with the granite country

rock, there is a band of very perfect graphic granite. The minerals occur both in the quartz and in the feldspar, but for the most part along the outer portion of the dike.

Gadolinite is the most abundant of the minerals and occurs in crystals and masses of irregular shape, sometimes weighing as much as 200 pounds, single crystals having been found that weighed over 70 pounds. One mass of allanite was found weighing over 300 pounds, and correspondingly large quantities of fergusonite, thoro-gummite, etc.

The radioactivity of some of these minerals is manifested by tanning the faces and arms of those who mine them.

The property is now controlled by parties who mine only such quantities of the minerals as are needed to furnish the incandescent glower used in the Nernst lamp.

There are other mounds of similar origin and structure in the vicinity in which small amounts of these minerals have been found, but so far no other locality has given promise of yielding them in commercial quantities.

The massive limestone of the Ordovician is very variable in character, and much of it has no special value as structural material. There are, however, in that portion of the formation called by Comstock the Hoover division a series of semi-marbles which give promise of yielding a large amount of very valuable structural and ornamental stone. These Burnet or San Saba marbles are even-grained, tough, and compact, and admit of a fine polish. Some are homogeneous in tint; others are variegated. The colors are white, pink, buff, and several shades of gray and blue. They occur at various points in Llano and surrounding counties, and it is only a matter of time when they will become the basis of a considerable industry.

The only ores of value that are found in connection with the Cambro-Ordovician rocks are the beds of hematite and

limonite iron. These occur at many localities through the Llano region, and analyses show that many of them are high in iron, although a number are also high in phosphorus.

Up to the present time, however, little or no prospecting has been done on the various outcrops, and we know, therefore, very little as to the real extent or value of the deposits.

The Carboniferous rocks of the west are deposits of the sea, with little or no admixture of materials derived from the land, and they show no coal-beds nor deposits of petroleum, nor are any mineral deposits known in them.

The rocks of the Pennsylvanian in northern Texas, however, toward which the wash from the land surface contributed a great amount of material, contain deposits of coal, petroleum, and gas which are of very great value.

The Bend division, which is the continuation of the Caney shale of Oklahoma, like it, is highly bituminous and yields both oil and gas. Up to the present the yield from wells drilled into it in our territory has not been very large, but is sufficient to prove its character as an oil-bearing formation and to warrant a careful investigation into its structure in an effort to locate more favorable points for drilling.

This is especially true of the region east of the Lampasas geanticlinal, where the Bend is overlain by the Cretaceous.

In the Strawn division, which overlies the Bend, we find the seam of coal which has been worked for so many years in Parker, Palo Pinto, and Erath counties. While the bed is not as thick as many of those of Oklahoma, the coal has proved very serviceable and an acceptable fuel. The outcrop of the coal-bed, beginning at a point a few miles west of Decatur, extends southwestwardly across the counties named until it passes under the Cretaceous hills northwest of Stephenville. Mines have been opened at different points, but those along the Texas and Pacific railroad have

been most fully and successfully developed, probably because of the better facilities for transportation.

The Cisco, or upper division of the Pennsylvanian, of this region also carries a seam of coal, the outcrop of which can be followed from Bowie across Jack, Young, Stephens, Eastland, Brown, and Coleman counties to the Colorado river. The thickness of the seam is variable and in places it is too thin or too impure to work, but the extension of rail lines along it has caused its development at the more favorable localities and it is furnishing large quantities of excellent fuel. From present indications it bids fair to rival the lower seam in production.

The economic value of the Cisco division is not, however, found alone in its coal-bed; for to the westward it is the principal source of the oil and gas which are being produced in the region extending from Burkburnett, on Red river, to the Texas and Pacific railroad. During the last four years a number of oil-pools have been opened up in this region, including Petrolia, Iowa Park, Fowlkes, Electra, Burkburnett, and Moran.

The oil is of very high gravity and has a paraffin base. The wells are from 700 to 1900 feet or more in depth, and the production for 1913 was nearly 9,000,000 barrels.

The indications are that other producing pools will be found, and that the oil territory may spread nearer to the foot of the plains.

Vast quantities of natural gas are also found, and many cities and towns are now being supplied with it from wells drilled into this formation.

In all such occurrences the geologic structure is one of the prime factors. As we have seen, we have here a synclinal basin, the axis of which is probably east of the border of the

plains. The oil was deposited either already formed or as fatty matters derived from partial decay of animal and vegetable remains which were later transformed into oil and gas by fermentation or pressure-distillation, and these oils and gases, acting under natural laws, are concentrated in the more elevated portion of folds in the inclosing beds. No great amount of orogenic action has occurred here, and consequently the lines of uplift are small and often masked by later deposits. While this is true, the chances of finding oil and gas along such lines are so much greater than in ordinary "wild-catting" that every effort is being made to locate them and so lessen the chances of getting dry holes.

The region is now being carefully studied by several corps of geologists who are endeavoring to locate such existing structural lines as may in any way influence the concentration of the underground oil supply, as an indication of suitable places for drilling new wells.

In the trans-Pecos area the limestones of Permian age form the country rock of the ore bodies which have been worked for many years by the Presidio Mining Company at the mines on Cibolo creek northeast of Presidio del Norte. The silver ores which occur here are found in cavern-like openings or chambers in the limestones which are connected by fissures of less or greater width. These mines have been the most reliable and productive yet found in Texas, and have been worked since the year 1884.

The principal ore is horn silver or silver chloride, although pockets of galena rich in silver also occur, together with smaller amounts of other lead and zinc ores.

Similar deposits of zinc ore also occur in these limestones in this region, but have not yet been mined to any extent.

The principal mineral deposits occurring in connection

with the Permian rocks of north Texas are gypsum, salt, and copper; while west of the Pecos, in addition to the mineral deposits, oil and sulphur are also found.

The copper of this formation does not occur in veins as in the older rocks, but it was deposited in beds of blue clay at or near the time they were laid down beneath the waters. Whatever may have been the origin of the copper, it was probably carried in solution in the percolating waters and precipitated by the action of the organic matter carried out with the clays and sands.

It now occurs scattered through these clays in the form of sulphide of copper, which, near the surface, has been oxidized and now shows stainings of copper carbonates. In places it is more concentrated and is found in the form of nuggets or as replacements of fragments of wood or even whole trunks of trees, and of the bones of animals. Such deposits are frequently of considerable value.

The beds of clay are from three to four feet thick and are continuous over long distances. The copper disseminated through them is more abundant in some parts than in others, and in places is in sufficient quantity to make mining possible if the ore could be separated from the clay.

There are three distinct horizons at which the copper occurs. The first is in the Wichita beds, and its outcrop begins on Red river near the mouth of Cache creek (where it was first observed by Captain Marcy in his exploration of Red river in 1852), and extends southward through Archer county.

It is from these beds that the largest amounts have been taken. Pockets carrying several thousand pounds of high-grade ore were found some years ago and the material shipped, but nothing has been done with them lately.

The second bed is found in the Clear Fork division, ex-

tending from Buffalo Gap northeastward by way of California creek in Haskell county on to Red river.

The upper beds are in the Double mountain division and occur at Kiowa peak, Buzzard peak, and Cedar mountain, at the head of Raggedy creek and the north side of Pease river.

The occurrence of this copper in this manner is somewhat similar to that of the copper ore found in the Permian of Germany, which has been the basis of an industry employing 50,000 men and producing both copper and silver.

The Texas clays are not so bituminous as those of Germany, the beds are thicker, and the copper ores are for the most part disseminated through the entire thickness of the bed instead of being concentrated within the bottom twelve or fifteen inches. In the Mansfeld district, also, vast quantities of water are encountered in mining the copper shales; while in Texas the ore occurs in a region so dry that there is not sufficient water supply to wash and concentrate the ore properly.

Only the richer pockets have so far been utilized, and these are so separated and of such uncertain occurrence that no regular mining has been done on them. It is hardly probable that this copper, vast as it must be in aggregate amount, will be utilized until some cheap process of separating the ore from the clay has been devised.

The gypsum deposits of the Permian cover an extensive area and are of such great thickness that they are practically inexhaustible for all uses now known. They are found both in the region lying east of the Staked Plain and in the valley of the Pecos west of that plateau. On the eastern side of the Plain they extend from Red river to the line of the Texas and Pacific railroad in a belt from 20 to 50 miles wide. The beds are of varying thickness. Some are no

thicker than a knife-blade, and others are 30, 40 and even 60 feet in thickness. The material is found in clear transparent masses of selenite, in compact snowy beds of alabaster, in beautiful rounded masses of thin rose-like leaves, colored reddish pink, known as "rose gypsum," in massive beds, and as a pulverulent sandy mass known as gypsite. This last is the material of which the cement plasters are made, and is the variety which is at present most sought for manufacturing purposes, being the basis of operations of several large mills near Quanah.

The deposits west of the Plain are of equal value with those east, but, owing to their location, have not yet been opened up.

This gypsum is an integral part of the geologic history of our State. It marks distinct stages in the evaporation of the waters of the Permian sea when it was so shut off that not enough fresh water could enter to hold these mineral salts in solution and thus the gypsum and salt were deposited.

The gypsum-beds, by reason of their insolubility and resistance to erosion, form permanent benches throughout the area, while the salt-beds, because of their ready solubility, are not so well known. The salt manifests itself, however, in numerous salt springs and wells in the Permian area. All the rivers and streams passing through the area are more or less impregnated with it, so that at low stages some of them are almost brine. For miles at such times the banks of the rivers are as white as snow. Salt Croton creek is especially briny. All the rocks around the falls above its junction with the Brazos are incrusted with salt, and the water of the pool below the falls is of a density approaching that of Great Salt Lake. Salt is deposited along the banks in sheets and is gathered for use. This salt, of course, has its origin in the deposits in the clays of the Permian, from which it is dis-

solved by percolating waters, brought to the surface, and redeposited.

Beds of rock-salt also occur, but they have been utilized only by wells at Colorado Springs, in Mitchell county, where, in boring for water, rock-salt was encountered at a depth of 850 feet. Below this depth there were found, within a distance of 250 feet, strata of rock-salt with a total thickness of 140 feet. Water is found in connection with the salt-beds, and this rises to within 170 feet of the surface. It is a saturated brine and seems inexhaustible. It is pumped to the surface and evaporated, and has been utilized for many years in the manufacture of a fine grade of salt.

In the region around San Angelo where the rocks of the Albany division are found in good exposures they contain beds of shales and limestones that are distinctly petroliferous. Asphalt has been reported from wells in this vicinity, and it is probable that the indications will lead to the sinking of test wells at least.

Between the Delaware mountains and the Pecos river both oil and sulphur are found at numerous localities in connection with the Permian deposits, and in some cases apparently in connection with those of Quaternary age as well.

Several wells drilled in the Toyah valley have encountered small quantities of oil at comparatively shallow depths, and deeper drilling has shown a number of petroliferous beds underlying it. The uppermost beds are found in connection with the pulverulent gypsum and other late deposits which form the surface materials, while the lower beds are either Permian or Cretaceous. So far only wells of small production have been brought in in this area.

Sulphur deposits occur in the same connection, being found mingled with the gypsum and impregnating other beds adjacent to or lying between the oil-sands.

In the valley between the Rustler hills and the Delaware mountains there are also sulphur impregnations in the gypsum, but these have not been so thoroughly prospected as the beds east of the Rustler hills and the Toyah valley.

While the sulphur occurs in sufficient quantity to be commercially valuable, it is at present too far from market to make its development attractive in competition with the great deposits of the coast country of Louisiana and Texas.

The deposits of economic value occurring associated with rocks of the Cretaceous include quicksilver ores, coal, petroleum, salt, gypsum, and artesian water-beds.

The presence of cinnabar in the trans-Pecos region was known to the Indians, who used it in painting their faces and bodies, but all search for the place from which they obtained it was in vain for many years. In September, 1894, a large piece of the mineral which had been found in the southern part of Brewster county was given me and was presented before the Texas Academy of Science at Austin as the first find of mercury in Texas. In 1895 Professor Blake made an examination of the region, which had then been located for mining mercury, and his is the first published account of it. This was followed by the location of other prospects in the neighborhood, but, owing to the scarcity of fuel and the distance from transportation, development was rather slow for a time. Part of the trouble also grew out of the land conditions and the State Mining Law, as in the case of prospecting for gold and silver.

Several good mines, however, were opened and furnaces erected which have produced large amounts of quicksilver. At present only one of them is active.

The production is from the vicinity in which the ore was first discovered, but prospecting has shown several other localities where the mineral occurs apparently in commercial

quantities, and it is probable that a stronger demand for the metal and better transportation facilities will bring about a considerable increase in mining and smelting in this region.

This ore occurs in connection with rocks of the Cretaceous series which apparently were more or less faulted and shattered by movements accompanying the intrusion of the igneous rocks which we now find breaking through them at various places and interbedded with them as sills at others. In the crevices and openings thus formed the mercury was deposited and is found in several forms, the principal one of which is cinnabar. It is found in the Eagle Ford shales, Buda limestones, Del Rio clays, Washita and Edwards limestones, and, while the exact manner of its occurrence may vary somewhat with the different classes of material in these beds, the ore persists in depth as far as mining has yet been carried.

The coal deposits of the Cretaceous are found in connection with the Taylor marls occurring in the Big Bend of the Rio Grande and in the vicinity of Eagle Pass. Coal has also been found in the vicinity of the Eagle mountains and near Fort Hancock some thirty miles east of El Paso, but, so far as now determined, these latter are not of economic importance.

The coal occurring in the San Carlos field and southeastward in the Chisos mountain region, although it may not occur in sufficient bodies nor of good enough quality to warrant its being mined for shipment as fuel for general use, will certainly, when this region is opened up as it should be, become of very considerable local value as fuel supply for the quicksilver ores, for steam uses, and for the generation of electric power.

The deposits around Eagle Pass are of greater value. We have here a bed of coal which, with one or more part-

ings and a thickness in many places of six feet, underlies a territory probably fifty square miles in area on the Texas side of the Rio Grande and a far larger area in Mexico. It is somewhat ashy in places, but, on the whole, when it is properly mined and cleaned it is a very acceptable fuel for household and steaming purposes. It has been mined for many years in a small way, and in the future it will certainly form a cheap and desirable fuel supply.

The oil deposits of the Cretaceous occur at various horizons and are of great value.

In Burnet county the sandy limestone of the Paluxy is, in places, saturated with asphaltum derived in all probability from seepages from the underlying Bend shale. This occurrence and the wells drilled in the vicinity of South Bosque, each of which yields a few barrels of oil daily, suggest the possibility of similar occurrences of oil at other localities east of the Lampasas anticlinal when structural conditions are favorable.

In west Texas small quantities of asphaltum are found in connection with the Washita limestone, but, so far as is known, this series carries no workable oil deposits in this region.

The first oil found in the Cretaceous was in the Taylor marls at Corsicana and San Antonio, and the former has furnished a field for long-continued development and is still producing. It yields oil of two grades: one very heavy and asphaltic; the other, though also of asphaltic base, much lighter in gravity. The gas of the Mexia region is also found in the Taylor marls.

On the eastern line of the State, in Marion county, we find the western extension of the Caddo oil-field of Louisiana, which has produced such large amounts of oil. This oil

also occurs in the Taylor marls and Woodbine sands of the Cretaceous, and a proper study of structural conditions will probably result in the finding of other continuations of this field in other parts of eastern Texas. It is of a paraffin base and is of high gravity.

Still another occurrence of oil in the Cretaceous is found in the Cline asphalt-bed, where the highly fossiliferous limestone of the Anacacho is found strongly impregnated with a high-grade asphaltum.

The most productive beds are those connected with the limestone deposits, and the occurrence of the oil in these beds lends color to the theory that they were produced from the minute unicellular organisms of that time and deposited synchronously with the limestones with which they are now associated.

A very interesting occurrence, and at the same time one of very considerable commercial value, is that of the salt deposits associated with beds of the upper Cretaceous. These salines, as they are called, are found at various places in eastern Texas and Louisiana, generally as outliers from the main body of the formation, and surrounded, if not covered, by deposits of the Tertiary. Among the best known of them are Grand Saline in Van Zandt county, Brooks and Steen salines in Smith county, and the salines in Anderson county west of Palestine. The salt in these salines exists as deposits of pure rock-salt of dome shape. Borings at Grand Saline indicate a length of nearly a mile for the bed of salt, which has a thickness of over 200 feet. Similar salt-domes also occur in the Tertiary beds themselves in connection with the oil and sulphur. The way in which these accumulations were brought about is still a problem, but there is little doubt that they are all directly connected in some manner.

All of the salines named have produced salt at different times, and Grand Saline and Anderson saline have been steady producers for years.

While gypsum occurs in quantity in connection with the clays of the Cretaceous, it is usually in separated masses or individual crystals and fragments. In the Malone mountain, however, it occurs as a great body of gypsite and massive gypsum.

The gypsum in this locality seems to belong to two or three different horizons. The upper beds occur in connection with the Washita, while similar beds occur also in the series of rocks referred to the Glen Rose or Fredericksburg. This occurrence is without parallel in the Cretaceous of Texas, but a somewhat similar condition has been brought to light by recent oil-wells drilled on the Panuco river west of Tampico.

While the Cretaceous has added its full quota to our comfort and convenience by the materials of economic value preserved within its sediments, it has given us in addition a boon greater than all this in the belts of water-bearing sands which spread over so large a portion of the State, and which are not only the source of the beautiful creeks and rivers of central and southwestern Texas, but of innumerable artesian wells scattered over a far greater area.

The Trinity, Paluxy, and Woodbine sands are all to a greater or less extent water-bearing, and throughout a large portion of their productive area they yield water well adapted for all purposes.

To the east and south of the outcrop of these lower sands for a distance of 75 to 100 miles they yield a supply of water which flows from the wells in many places; and even when the surface has too great an elevation to permit this, as in the Edwards plateau, the water can easily be pumped to the

surface and thus made available where all other supply is lacking.

This in itself is ample warrant for a very close study of the geology of the region, since in many places they form the only lasting and sufficient supply obtainable.

The minerals of the Tertiary include iron ores, gypsum, salt, sulphur, tripoli, and fullers' earth, together with such other important substances as lignites, petroleum, and natural gas.

The iron ores of east Texas are wide-spread in their occurrence, their quality is excellent, and the aggregate amount available for mining and shipment is possibly greater than that of any of the other States of the Union outside the Lake region. These deposits are on or near the surface, and the areas underlain by them, which were carefully mapped by the State Geological Survey, aggregate nearly 1000 square miles.

These ores are all connected with or derived from the Marine stage of the Eocene Tertiary. This stage is markedly ferruginous throughout its entire extent. It still carries in places large amounts of greensand which represent those portions of the original amount deposited in the sands and clays of this period which have escaped the oxidation, solution, and redeposition through which the vastly greater portion of this glauconitic material has been transformed into iron ores, ferruginous conglomerate, and sandstones.

The ores are of two general forms, called from their structure the nodular and the laminated. The former occurs usually embedded in sands in the form of nodules or boulders from a few inches to one or two feet in length. The laminated ores occur in thin laminæ of dark brown or chestnut color, sometimes interstratified with similar laminæ of bright yellow.

The deposits vary greatly in thickness, the laminated ores being more regular in deposition than the nodular, but both occur in workable quantities in many localities. The ores are limonites, or brown iron ores, and the contents of metallic iron are frequently over 50 per cent.

These ores have been worked for many years. Prior to the Civil War small bloomaries existed where the ores were smelted and iron utensils were manufactured. During the war the number of these increased, but most of them were shut down at its close. Later more modern furnaces were erected at Rusk, Jefferson, and elsewhere; but on account of the high cost of fuel, and with the coming in of strong outside competition by reason of better transportation facilities, these were closed down one by one until not a single one remains.

The ores, however, are now in process of development, and if plans which have been outlined in the press are carried out they will be carried to the Coast, where cheap fuel will meet them, and will there be smelted and manufactured; or they may be shipped from the Coast by water to northern points where furnaces exist and cheap fuel is at hand, until such time as conditions warrant the building of furnaces in Texas.

The quantity of the ore is so vast and its quality so good that these deposits will in due time be of great commercial advantage to the State.

The brown coal or lignite deposits are principally confined to two of the divisions of the Tertiary. The lower, from the prevalence of these deposits, has been termed the Lignitic; the upper is the Yegua clays. Lignite is also found in the Fayette sands and in the Marine beds, but in thinner and usually less important deposits.

These brown coals do not occur in such continuous beds as we find in coals of the Carboniferous, but are usually in lenticular masses, some of which are of very considerable extent but nevertheless limited in comparison with older coal-beds. They were probably the results of deposition within local basins scattered over the Tertiary area, and with the shifting of these basins we find a corresponding change in the beds of brown coal. The beds have thicknesses of from a few inches to twenty feet, beds of six to twelve feet in thickness being not uncommon. Since the Tertiary belt stretches diagonally across the State from the Sabine to the Rio Grande and these brown coal-beds occur throughout its longitudinal extent, the total amount of coal available is very great. Owing to more favorable conditions of deposition, by far the greater amount of this coal lies east of the Colorado river, but the beds west of that stream are both numerous and of good thickness.

These brown coals carry a much larger percentage of moisture than do the older coals, and they have the quality of slacking when drying on exposure to the air. While this quality is a distinct disadvantage, they can be used satisfactorily as fuel.

Mines have been developed at various localities, and the annual production is now about equal to that of the Carboniferous coal.

During the progress of the State Geological Survey, extensive investigations were carried on in an effort to find ways of utilizing this abundant and cheap fuel supply. It was found that with proper arrangement of fire-boxes and draft it could be used advantageously in steam-making, both for steam-plants and locomotive fuel; and had not the discovery of oil given temporarily a cheaper and better fuel,

there is no doubt that the present development of the lignite deposits would have been much greater than it is. The use of oil as fuel has, however, only postponed the day of usefulness of the brown coal; for, with the exhaustion of the oil or its withdrawal from fuel uses, we shall be compelled to fall back on the lignite. The delay has really made for its better economic use, since it has made new methods available which add to its efficiency with corresponding decrease in cost.

It is probable that the near future will see it used both under stationary boilers and on locomotives as a powdered fuel sprayed into the fire-box in somewhat the same manner as oil is now sprayed. Its greater use, however, will be in the generation of electric power which will in time take the place of much that is done with steam. The adaptability of the lignites for this purpose has been fully proved by the government's experiments in the manufacture of producer gas from it. This producer gas, by means of gas-engines, can be made a source of electric power at a cost lower even than that of water-power plants. Since these deposits cross the entire State, electric-power plants located in the vicinity of the mines could use the coal as mined and transmit the power over its entire extent east of the Pecos at least. This, it seems to me, is our future hope for cheap fuel.

This discovery and development of the oil-pools of the Coastal strip have greatly aided the general development of the area in every way and added very materially to the wealth of the State.

The existence of indications of oil in the area was recognized half a century before the bringing in of the Spindletop gushers, and there was a small production in Nacogdoches county fifteen years before the Lucas well came in. This well, however, stimulated the search for oil in all likely

and many unlikely places and resulted in the discovery of many pools of greater or less extent and productivity.

All of this oil, so far as has been determined, occurs in the sands and shales of the Tertiary. Beginning with the Marine stage, we find that it furnishes the wells near Melrose, which have only a small production, and this is characteristic of all wells getting oil in these beds. While the Yegua has not as yet yielded any oil, it is the gas-bearing series of the Tertiary. Wells drilled into it in Washington and Fayette counties have given heavy flows of gas, as did the wells at Aguilares east of Laredo. There are doubtless many localities in the area underlain by these beds where gas-fields of economic value will be found when they are properly prospected.

The most of the oil that has been found in the Coastal area is in connection with the upper Tertiary. In a few wells fossils have been found that indicate the presence of deposits of Jackson age, but by far the greater number of wells in the gusher-fields strike their supply of oil in beds of the upper Miocene or Pliocene. This is true of Spindletop, Sour Lake, Saratoga, Batson, and Humble, and of the Louisiana fields as well. The oil-pools are of rather limited extent, usually less than 800 acres. They are each apparently located at the apex of a subterranean dome and are connected in some unexplained way with deposits of rock-salt, gypsum, and sulphur. The cause of this doming has not yet been determined; but as we learn more of the underground geology of the Coast country through the interpretation of the results obtained in drilling deep wells, we are more and more confronted with the fact that prior to the beginning of the era in which the Coast clays, which now present a surface so nearly level, were laid down, the preceding beds had been folded and eroded. Thus the floor on which the Coast clays

rest is very uneven, and it is highly probable that the formation of the domes was connected with the earth movements of the Pliocene.

The production of the oil-fields of the Coast has been enormous, and there is still a possibility, if not a strong probability, that other fields may yet be found in this region which will yield quantities of oil equal to many of those already exploited.

The mineral which occurs most abundantly in the Coast country is salt. It is preëminently the mineral of the domes and is usually found in them, whether oil and sulphur are present or absent. The beds vary in areal extent and are of such great thickness that no well has ever penetrated them far enough to find their lower limit. The rock-salt of these deposits is of very pure quality.

The prospecting for oil has brought to light many extensive deposits of rock-salt in our Coast country. The most important of these as known at present occur at Dayton, Pierce Junction, Blue Ridge, and Damon's Mound. There are many other localities, for similar beds, some of them of great extent, have been found in nearly every oil-field; but these are of special value by reason of their suitability for actual development and because of being uncontaminated by oil. Their areas have been fairly well defined by drilling, and wells have penetrated them to depths ranging from 200 to 2100 feet. It is estimated that these deposits alone would furnish more than one billion tons of salt.

In connection with the superficial deposits of the lower Rio Grande country we find the important salt lakes, the Sal Vieja and the Sal del Rey. The Sal del Rey, which has been the source of salt supply for the lower country and northeastern Mexico for many years, is some five miles in circumference and has a depth of only three or four feet.

The bottom of this lake is solid rock-salt, and the water a very concentrated brine.

Sulphur also occurs in variable quantity in connection with the oil and salt of the different Coast fields. In some places it is found simply as crystals disseminated through the sands, at others in more massive form mingled with gypsum or inclosed in cavernous limestone. It occurs in commercially valuable deposits at several localities, but the only one of these as yet developed in Texas is at Freeport on the Brazos river, where the sulphur is mined by a process of pumping superheated steam into it and melting the sulphur, which is then pumped to the surface and becomes solid on cooling. These deposits are most favorably located for development and will be a prominent factor in the world's supply of sulphur for many years.

While gypsum occurs in the various Coastal fields in connection with the oil, it is not often in such form as makes it available for mining.

There are, however, in southwestern Texas deposits of pure gypsum which are of economic importance. The principal of these is the Loma Blanca, a few miles east of Falfurrias. This hill, which is 75 to 100 feet high, is composed of pure gypsum, and its crest shows an exposure of clear, transparent selenite which covers several acres and has been proved by drilling to have a thickness of 1000 feet.

This occurrence is not the only one in the region, and the relation of these mounds to the Sal del Rey and other salt deposits lying at no great distance south of it is a most interesting problem.

Throughout the Coastal plain from the Sabine to the Rio Grande there exists in connection with the sandy layers of the upper Tertiary a supply of artesian water that is secondary only to that contained in the sands of the Cretaceous.

It furnishes the water supply for nearly all the Coastal cities, including Houston and Galveston, and yields great quantities of water for aid in irrigation and for farm and ranch supply.

The sands of the Eocene also furnish large supplies of water, and it is probable that the entire producing area of the Tertiary will equal that of the Cretaceous. Like the Cretaceous, some of the water obtained from the Tertiary is more or less mineralized, but the amount of pure water yielded by it is of immeasurable benefit.

Time forbids more than this hasty sketch of the various minerals and materials of economic importance which are found within the State, and many occurrences of local value cannot even be touched on. It is hoped, however, that what has been said of the geologic growth of our territory in its broader relations and individual conditions, of the great variety and wide-spread occurrence of mineral and other substances of economic value, and the evidence we have of the intimate relation of all these materials to this growth, will bring out the full force of the necessity for an accurate knowledge of the geology of the State as a basis for the work of the discovery and development of these resources as well as for the cultural results which grow out of the study of the subject.

EDWIN THEODORE DUMBLE.

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The Rice Institute Pamphlet is published at Houston, Texa
and is issued in January, April, July, and October. It w
entered as second-class matter, April 15, 1915, at the po
office at Houston, Texas, under the Act of August 24, 191